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GLOBAL FORECAST MODEL TRIALS OF "FROZEN" PHYSICS,INCLUDING 1B CLOUD SCHEME

-Off-line tests and first parallel suite trial

by
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1 Introduction

This note describes the results of tests with the global forecast model of the "frozen" physics package used in the first "frozen" climate model version. All the components of the package as for the climate model were tested in 1 week trials for previous cases (December 1992, July 1991) at full operational resolution, with dynamics, horizontal diffusion and vertical diffusion as currently operational. These tests showed (see below) that reversion to the standard longwave package from the operational scheme with ECMWF-like transmissivities, gave unacceptable increases in the cold bias at upper tropospheric levels. It was therefore decided to test all the package except that the longwave radiation code would remain the ECMWF-like scheme. A parallel suite trial was carried out from 25/05/93 to 17/06/03 and this note documents the objective and subjective assessment of the trial.

The main drawback to the package was an unacceptable reduction in cloud amount due to the changed cloud scheme (unified model scheme 1B). Similar results from the use of the scheme in the LAM where frontal cloud rarely attained 100% cover, and moderate precipitation could be predicted from small cloud amounts, confirmed the unrealistic behaviour of the 1B cloud scheme and so a second parallel suite trial was run retaining the operational 1A scheme. This trial ran from 9/08/93 to 31/08/93 and the results are reported in Technical Report no. 76 (Hammon and Wilson, 1993).

2 "Frozen" physics package

The differences from the current operational physics are as follows:

short wave radiation:

layer clouds in all layers replaced by 3 cloud types only, determined by maximum cloud amount in specified range of model layers (figure 2.1) with cloud water paths summed over same range used to parametrize optical properties;

longwave radiation:

random overlap of layer clouds replaced by maximal overlap of contiguous cloud layers and random overlap of non-contiguous groups of clouds; the climate version uses the standard treatment of transmissivities whereas the operational (and parallel suite package) uses the ECMWF-like revised transmissivities;

boundary layer:

inclusion of rapidly mixing code which mixes heat and moisture over the full depth of an unstable boundary layer treated as a single bulk layer before locally mixing between separate model layers;

cloud:

the sub-grid scale probability distribution function of total cloud water fluctuations is now assumed to be a top-hat rather than triangular and the dependent variable changed from liquid water temperature to temperature; this results in different

functional forms for calculating cloud amount and cloud water/ice contents. (See FR Working paper No 152 (Wilson ,1993) for a comparison and details of the operational, 1A and frozen, 1B schemes.) The relative humidity thresholds have also been changed in the lowest three model layers from 0.925 to 0.95,0.9,0.85 respectively. (Above these lowest layers the threshold remains unchanged at 0.85). The net effect in the climate model simulations was to reduce low cloud amount over summer mid-latitude oceans where there was a problem of excessive albedo;

convection:

the downdraughts formed by evaporation of precipitation and now included. The rates of evaporation have also ben revised based on observations that evaporation from snow is generally more rapid than that from rain;

large-scale precipitation:

the evaporation has been revised as for convection. The threshold for precipitation formation has been reduced from 8 $x10^{-4}$ kg/kg to 2 x 10^{-4} kg/kg over sea, with the land retaining the higher value. Reducing the threshold leads to reduction in cloud particularly low cloud over summer oceans. The retention of a higher value over land reflects the larger number of CCN over land , and hence cloud water may be expected to reach larger values before precipitation commences. The treatment of ice precipitation has been made properly flux divergent (see UM Documentation paper 26, Smith, Gregory and Mitchell, 1993) with separate depletion of water and ice fractions.

3 Results from 1 week tests

These tests were performed by running a continuous assimilation for the week using archived operational acobs files. Forecasts were run daily out to T+144 and the T+0,T+24,T+72 and T+144 forecasts were verified against observations using the acobs files valid for the verification times, by running a single timestep assimilation in verification mode. (For details and a comparison with standard operational verification see FR working paper no 157; Rawlins,1993). Verification figures are thus obtained for the model levels (see figure 2.1 for locations) and are meaned over all 7 cases.

Temperature biases

A major model fault noticed after the operational implementation of the unified model was the cold bias through much of the troposphere, which was alleviated through the use of the revised ECMWF-like transmissivities. The reversion to the standard scheme reintroduces much larger cold biases at upper levels (10-15, ~350-100hPa) as shown by the Observed -model differences at T+144 for December (Fig 3.1a,b,c, dashed curves), especially in the northern hemisphere and tropics. (NB positive values indicate the model is *colder* than observed.) Similar results are found for July (Fig 3.2a,b,c ; note dashed now indicates the operational version). Retaining the ECMWF-like transmissivities removes this cooling whilst largely preserving the beneficial warming at lower model levels in the extra-tropical areas (Figs 3.1d,e,f , labelled "frozen2" and 3.2d,e,f, labelled "frozen4").

In the tropics there is a worsening of the cold bias between levels 3,4and 5 (~930-800 hPa) in both December and July whichever longwave scheme is used. (Figs 3.1b,e and 3.2b,e). This is due to the downdraught scheme allowing evaporation from higher levels and not just below cloud base, and there is some evidence for December of a corresponding warming due to reduced evaporative cooling at levels 1 and 2 ie below cloud base. These

tests indicate that 850hPa temperatures will probably be worse in the tropics.

A similar pattern is largely found at T+72 (Figs 3.3 and 3.4) with usually smaller biases. However note that the northern hemisphere operational control for December (Fig 3.3a) has a warm bias between levels 11 and 14 and the frozen package with standard radiation has an almost equal cold bias here. Overall the choice of longwave radiation favours retaining the ECMWF-like scheme. Results from a 3rd week test from last winter (30/01/93-05/02/93) confirm those from the earlier tests (Fig 3.5).

Winds

For the December week, the rms vector wind errors at T+24 from the frozen physics version are virtually identical to those from the control version, for the northern hemisphere north of 22N (Fig. 3.6a). However, at T+72 (Fig 3.6b) the frozen version has worse rms errors ($\sim 1 ms^{-1}$) at upper jet levels (levels 11 to 14, ie 300,250,200,150 hPa), especially compared to AIREPs. In the tropics there is a small improvement at lower levels with worsening at upper levels 9 to 14, at both T+24 and T+72 (Fig 3.7a, b). The southern hemisphere rms errors are also poorer for the "frozen physics" version at upper levels ,especially at T+72 (Fig 3.8b) when the verification against sondes and aireps indicate a consistent impact, whereas at T+24 (Fig 3.8a), the comparison against sondes shows the "frozen" version to be slightly better.

For July, the results are very similar and only T+72 are shown. The errors for the northern hemisphere (Fig 3.9a, full line) at levels 11 to 14 are now only slightly worse than for the operational version (dashed). In the tropics there is again a small improvement in the lower atmosphere and a degradation of up to $1 ms^{-1}$ at upper levels around 200hPa. The southern hemisphere also shows the rms errors at upper levels to be worse (Fig 3.10).

The indication of a possible worsening of the winds caused some concern and special attention was paid to the verification obtained from the longer parallel suite trial. However since the errors were worse for the December week a parallel suite run in summer may not be very representative.

4 First parallel suite trial - objective assessment

The parallel trial ran from 25/05/93 to 17/06/93 with forecasts made from 12Z data to T+120. Forecasts, every 24h, and analyses were verified against observations and meaned over the period. The variables verified were:

PMSL, T1.5m,	
temperatures	levels 850,700,500,300,250,200,100,50 hPa
heights	levels 850,700,500,300,250,200,100,50 hPa
winds	levels 850,700,400,500,300,250,200,100 hPa
relative humidity	levels 850,700,500 hPa

The results were obtained for the standard verification areas:

area 2, N Atlantic and western Europe
200 Northern hemisphere from 30N
300 Tropics, 30N-30S
400 Southern hemisphere from 30S

Forecasts from operational and parallel suites were also verified against their own analyses. The same parameters were verified as for the verification against observations with the addition of relative humidity at 950hPa, and for the same areas. A selection from the various results to illustrate the general impact of the trial package is given below. Most figures will show verification against observations since the verification against analyses gives essentially the same picture; also because of the deficiencies of the 1B cloud scheme an extensive discussion verification results is not worthwhile.

Temperatures

There are substantial reductions in the cold bias outside the tropics as shown by the mean errors at T+120 (Figs 4.01,4.02) with largest warming at lowest levels (850 and 700 hPa), of ~0.6K for the northern hemisphere. The rms errors are also better, by ~0.3K (6%) at 850 hPa , northern hemisphere. Similar improvements are seen for the southern hemisphere, with the substantial warming reaching up to 250hPa (Fig 4.02). In the tropics there is cooling at 850 and 700 hPa due to the downdraughts cooling by evaporation of precipitation . In the operational scheme the cooling is only allowed beneath convective cloud base. From this verification it appears that the operational model is too warm at 850 hPa and so the frozen physics version is better; however the 700hPa bias has been made colder and worse. There is also some increased cooling at 200 hPa and the rms error is also worse here. The general improvement in rms scores is apparent from Tables 4.1,4.2, particularly in the lower atmosphere with improvements, at T+120, of ~2-3 % at 500hPa and generally ~4-6% at 850hPa. The worst degrading is at 200 hPa in the tropics with increases in rms ~5 to 11% at various forecast periods.

Heights

The height biases are generally improved e.g. at T+120 (Figs 4.03,4.04) ,except at 850 hPa outside the tropics where they are slightly worse. The biggest improvements are ~7m at 250 hPa for area 2 and the northern hemisphere. Rms errors are also generally better for these areas and comparable in the tropics and southern hemisphere. Looking at all times and verifying against analyses as well as observations (Tables 4.3,4.4) the largest impact is found for the northern hemisphere and area 2 with improved rms of ~3-5% generally and peak improvement of 10% at 100 hPa.

Winds

Unlike the off-line week trials, assessed in section 3, there is little evidence for a degradation of rms scores around jet levels either at T+24 (Figs 4.05,4.06) or at T+72 (Figs 4.07,4.08). For area 2 there is a small worsening of the negative speed bias below 300hPa ; the negative bias at 500 hPa and above is worse in the tropics at T+24 (Fig 4.06) and by T+72 (Fig 4.08) the worsening is confined to 250 hPa and above. Rms vector wind errors are generally worse in the southern hemisphere (Fig 4.08, Tables 4.5,4.6). From tables 4.5,4.6 it is apparent that many of the changes are very small ~1% or less, with the main improvements in area 2 and the northern hemisphere again. The parallel suite trial has not shown the degradation for the northern hemisphere found for the 1 week tests. However the largest negative impact in the off-line tests was for December and in the parallel suite the (winter) southern hemisphere scores were generally worse .

Relative humidity

The moist bias is smaller for the trial for area 2 and the northern hemisphere (Fig 4.09, T+120) but is slightly worse for the southern hemisphere at 850 and 500 hPA (Fig

4.10) The moistening at 850 hPa in the Tropics appears to be an improvement as does the relative drying at 500hPa. The rms scores at T+120 are generally slightly better for the trial. This is generally the case for all times (Tables 4.7,4.8) , although the tropical rms is mostly worse when verified against analyses (Table 4.8).

Mean sea level pressure

Outside the tropics the mean bias shows a small deepening tendency (Figs 4.11,4.12). At earlier forecast periods (up to T+48) the operational generally has a smaller bias for area 2 and the northern hemisphere; for T+72 and beyond the operational and trial have approximately equal positive and negative biases. For the southern hemisphere the results are reversed with the trial having smaller bias up to T+48. The rms are generally comparable for all extra-tropical areas. The tropical bias is slightly less negative and the rms is better at most forecast times (Fig 4.12).

Surface temperature

The mean cold bias is improved for all areas outside the tropics, and is worsened in the tropics beyond T+24. Rms errors are better in all areas for all forecast periods.

Overall summary

Several of the differences between the trial and operational verification scores are actually quite small. However there was a general improvement in the lower atmospheric cold bias and surface temperature bias, which was reflected in a small reduction in height bias. Winds were not significantly changed in terms of mean speed bias and rms vector errors were generally comparable. A count of the rms scores which are better or equal to the operational for each variable verified and for each area (Table 4.9) shows the trial to be better in most areas for all parameters, except for winds in the southern hemisphere, northern hemisphere winds verified against analyses and tropical relative humidity verified against analyses. If the "frozen" physics were to be judged solely in terms of improved scores then the case for operational implementation would have been proved. However as shown in section 5, and FR working paper 152 (Wilson,1993) , the cloud predictions from scheme 1B are significantly too low with unrealistically large in-cloud cloud water contents. This part of the package has been rejected and a second trial carried out , retaining the operational cloud scheme which is more physically justified. The results from that trial do not show the beneficial warming and reduction in cold bias to the same extent (see FR Technical Report no 76, Hammon and Wilson, 1993). The greater release of latent heating from the 1B cloud scheme, particularly in the extratropics, is further evidence that a large proportion of the initial atmospheric cooling is due to insufficient diabatic heating (see FR Technical Report no 64, S F Milton, 1993). Further work should be aimed at understanding this problem and measures found to reduce or eliminate the spin-up of precipitation, which occurs in the extratropics, and so significantly reduce the model's cold bias.

5.SUBJECTIVE ASSESSMENT OF THE FIRST PARALLEL SUITE TRIAL OF THE "FROZEN PHYSICS PACKAGE"

Trial period 25/05/93 - 17/06/93

a) **Northern Hemisphere (North of 30N)**

Changes in the forecast mean sea level pressure and upper air fields were generally small in the Northern Hemisphere summer although some slight evolution changes were seen at T+120. Subjective assessment of these differences at T+120 was slightly in favour of the "Frozen Physics" trial forecasts.

Trial depressions tended to be very slightly deeper, mostly by 1 to 4mb later in the forecast period. The subjective impression is confirmed by the mean differences between trial and operational depressions listed in Table 5.1. below.

Trial jet maxima at 250mb tended to be slightly weaker up to T+72, as shown in Table 5.1 but in the later stages of the forecast, this bias disappeared. Subjective assessment of the jet evolution differences at T+120 slightly favoured the trial version.

	Depressions	250mb Jets
T+00	-0.1mb	0.0 knots
T+24	-0.2mb	-0.8 knots
T+48	-0.3mb	-0.8 knots
T+72	-0.6mb	-0.4 knots
T+96	-0.8mb	0.0 knots
T+120	-1.0mb	0.4 knots

TABLE 5.1 Mean differences (trial - oper) between trial and operational depressions and jets forecast in the Northern Hemisphere during trial period 25/05/93 to 17/06/93

The main impact of the "Frozen Physics Package" in the Northern Hemisphere was seen in increased numbers of showers over land and a marked decrease in the amount of low layered cloud, especially over the sea.

These differences are illustrated in Figures 5.01 to 5.04 by an example of one 24 hour forecast, verifying at 12Z 12th June. The British Isles chart for this time, shown in Figure 5.01, shows a depression centred near Clacton with the main frontal rain bands just clearing Southern England. The weather over England and Wales was cloudy with ocasional light rain or showers. The trial and operational rainfall and mean sea level pressure forecasts for T+24 are compared in Figures 5.02 (a) and (b) respectively. The trial forecast of light showers over England and Wales was an improvement on the operational forecast of dry weather except in the southwest.

The trial and operational cloud forecasts for 12Z 12th June are compared in Figures 5.03 (a) and (b) respectively. The output shows forecast low cloud(small dots) and medium cloud (small circles) of amounts greater than 4 octas. The British Isles chart

shows that there was a good deal of low and medium cloud over England and Wales in the northeasterly flow just west of the depression. These cloudy conditions were better predicted by the operational forecast. The operational forecast also predicted much more low cloud over the sea, especially around the anticyclone west of Iberia. The visual satellite image for 12Z 12th June, Figure 5.04, shows an area of stratocumulus west and southwest of Iberia associated with the anticyclone. This area is better represented in the operational forecast.

A second cloud forecast comparison is illustrated by Figures 5.05 and 5.06. The trial and operational cloud forecasts for T+24, verifying at 12Z 15th June, are compared in Figures 5.05 (a) and (b) respectively. The operational forecast predicted an extensive area of low cloud over the sea to the southwest of the British Isles and a definite frontal band of medium cloud just west of Ireland. Both of these features were not predicted by the trial forecast. The visual satellite image for 12Z 15th June (Figure 5.06) confirms that the operational forecast was better.

The forecast differences described in these two examples were a regular feature of the trial assessment. The increase in showers overland in the trial forecasts was usually beneficial especially in the cooler airmasses but sometimes was overdone in warm, humid airmasses. The mean convective and dynamic accumulations for the Northern Hemisphere trial and operational forecasts are compared in Figures 5.07(a) and 5.08(a) respectively. These graphs show an overall increase in the amount of convective rain forecast with a corresponding small decrease in dynamic rain accumulations.

The decrease in the amount of low cloud predicted in the trial forecasts amounted to 10%-16% and was noticeable especially over the sea. The verification of cloud amounts is difficult over the sea and depends on satellite imagery but assessments of the individual forecasts indicates that the decrease in low cloud is too large. In trial forecasts, a full cover of low cloud was rare even in frontal bands. In contrast, low cloud, especially in model levels 1 and 2, often seems too widespread in operational forecasts. Whilst a drying and marked decrease in the amount of cloud in the two bottom layers could be beneficial, any drying at 850mb could be disastrous for the prediction of stratocumulus.

There was also a smaller decrease (2%-6%) in trial medium cloud depicted by narrower frontal cloud bands. In some of the trial forecasts rainfall appeared to be falling from less than four octas of cloud, showing a tendency for the low cloud to be "rained out".

The mean amounts of low, medium and high clouds in the trial and operational forecasts from the parallel suite trial for the period 25/05/93 to 17/06/93 are listed in Table 5.2 below.

Time	Low cloud		Medium cloud		High cloud	
	trial	oper	trial	oper	trial	oper
T+00	19.7	29.1	14.0	16.3	18.6	19.5
T+12	20.8	32.8	15.5	18.3	22.8	23.7
T+24	23.9	36.9	16.5	20.1	24.5	25.8
T+36	23.5	38.4	16.8	20.6	24.7	25.5
T+48	-	-	-	-	26.0	27.0
T+72	25.8	41.0	17.5	22.8	26.8	27.5
T+96	-	-	-	-	26.8	27.7
T+120	26.0	41.9	18.1	23.8	26.8	27.5

TABLE 5.2. Mean percentage of low,medium and high cloud in the Northern Hemisphere forecast during period 25/05/93 to 17/06/93

Overall, the asessment favoured the trial ("frozen physics package") but with reservations about the large reduction in the low layer clouds composed of relatively warm water.

b. **Tropics (30N - 30S)**

Many differences were noticed in the subtropical jets in the Southern Hemisphere between 25S and 30S, T+72 onwards. Changes in evolution meant that the trial jets could be either weaker or stronger than the operational jets but there was a tendency for the trial jets to be stronger. The assessment of these differences (often >10 knots) relied on the respective analyses plus a few observations. The subjective assessment was slightly in favour of the operational jets.

The mean convective and dynamic rainfall accumulations are shown in the graph in Figure 5.09. This graph shows that the overall rainfall amount in the tropics changed little but there was a slight switch from convective rain to dynamic rain. In the subjective assessment, however,the most noticeable difference was the increase in the number of light/moderate showers predicted both over the sea in the ITCZ and over land.

Figure 5.10 (a) and (b) compare the trial and operational rainfall forecasts over Africa and South America at T+24, verifying at 12Z 12th June 1993. The main impact of the "frozen physics package" over Africa can be seen in the increased number of light / moderate showers predicted over Central Africa at 10N 20-30E and over the Congo at 10-20E just south of the equator. Rainfall over Africa is difficult to verify due to lack of observations and depends on satellite imagery. The meteosat visual and infra red satellite pictures for 12Z are shown in Figures 5.11 (a) and (b) respectively. The trial forecast was better for the Congo but the light showers predicted 10N 20-30E look too widespread. Another interesting feature was the area of showers predicted by the trial forecast over Northern Africa at 10E between 20N and 30N. The satellite imagery indicates an area of mainly high cloud over this area with perhaps two small convective cells at about 25N 10E. This may justify the trial forecast although the light showers predicted are obviously too widespread.

Figures 5.12 (a) and (b) compare the trial and operational

rainfall forecasts over Australia and Asia at T+24, verifying at 12Z 12th June. The main impact shows in the greater number of light/moderate showers over the South Pacific Ocean and overland in the Himalayas and Northern India.

c. Southern Hemisphere (south of 30S)

Changes in evolution between trial and operational forecasts were more noticeable in the Southern Hemisphere especially T+72 onwards. Overall, the trial ("frozen physics package") forecasts were slightly more cyclonic than the corresponding operational forecasts, i.e., depressions tended to be slightly deeper and jets stronger. The mean differences between trial and operational depressions and jets are listed in Table 5.3 below. This Table shows the tendency for the trial depressions to become deeper during the forecast and for the jets to become stronger. The subjective assessment of these evolution differences based mainly on the respective analyses, favoured the operational forecasts.

	Depressions	250mb Jets
T+00	-0.3mb	0.1 knots
T+24	-0.5mb	0.7 knots
T+48	-0.9mb	1.4 knots
T+72	-1.0mb	1.2 knots
T+96	-1.0mb	1.6 knots
T+120	-1.3mb	2.7 knots

TABLE 5.3 Mean differences (trial - oper) between trial and operational depressions and jets in the Southern Hemisphere.

There was a reduction in the amount of low cloud in the trial forecasts but the differences were smaller than in the Northern Hemisphere. The mean differences between trial and operational cloud amounts are listed in Table 5.4 below.

	Low cloud		Medium cloud		High cloud	
	trial	oper	trial	oper	trial	oper
T+00	32.5	37.1	23.8	28.3	23.9	24.8
T+12	33.9	38.4	26.4	31.8	26.1	26.9
T+24	34.5	39.5	27.2	32.6	27.9	28.6
T+36	35.0	39.8	28.1	34.0	29.3	29.9
T+48	34.8	39.1	28.5	34.6	29.8	30.6
T+72	34.9	38.0	29.6	36.2	31.2	31.6
T+96	34.8	36.4	30.3	37.1	31.8	32.1
T+120	34.5	35.4	30.5	37.1	32.2	32.4

TABLE 5.4 Mean percentages of Low, Medium and High cloud forecast in the Southern Hemisphere during the period 25/05/93 to 17/06/93

Figure 5.13 (a) and (b) compare the trial and operational mean sea level pressure forecasts over the South Atlantic Ocean for T+120, verifying at 12z 7th June 1993. The main area of

interest is between 50S and 60S, 10-30W, where the trial forecast has predicted a much deeper depression, 962mb, than the operational forecast, 992mb. This difference of 30mb was the largest difference between the two versions in the parallel suite trial. As may be expected, neither version was correct! The operational analysis, Figure 5.14 showed a depression, 980mb further south at 64S 28W. The trial analysis was the same.

Figures 5.15 (a) and (b) comparing the trial and operational forecast 250mb wind isotachs for the same verifying time over the South Atlantic, show several differences between the forecast jets. The main differences between the jets and the verifying analyses are listed in Table 5.5 below.

Position	Trial jet	Oper jet	Analysis	Assessment
58S 30E	127 knots	143 knots	116 knots	trial closer
38S 25E	119 knots	105 knots	109 knots	oper closer
50S 20W	133 knots	no jet	no jet	oper closer
35S 85W	129 knots	110 knots	104 knots	oper closer

TABLE 5.5 Comparison between T+120 forecast trial and operational 250mb jets in the South Atlantic, verifying 12Z 7th June 1993.

(d) **Zonal mean cross-sections and field charts**

The zonal mean cross-sections and field charts described in this section are meaned over the full period of the parallel suite trial, 25/05/93 to 17/06/93.

(i) Zonal mean temperature cross sections (Figures 5.16 -5.17)

Temperature changes in the Northern Hemisphere summer were dominated by the warming near the surface at 12Z, which could be associated with the marked reduction of low cloud. This warming was apparent even early in the forecast period, shown by a mean increase of 0.1C below 900mb at 50N in the analysis (Figure 5.16(a), rising to 0.5C by T+24 (Figure 5.16(b)). This low level warming continued to intensify and spread upwards in the atmosphere during the forecast, reaching a mean increase of 1.1C near the surface and 0.2C at 550mb by T+120 (Figure 5.17(b)).

A similar but weaker low level warming can also be seen in the Southern Hemisphere winter at 40S-50S, reaching 0.1C at 40S-50S at analysis time near the surface (Figure 5.16(a)) and increasing to 0.5C by T+120 (Figure 5.17(b)). In the Southern Hemisphere, the frozen physics package represents a mean warming of the troposphere of 0.2C or more by T+120.

In the Tropics, there was a marked warming centred on 230mb with a marked cooling at 150mb, which resulted in a raising of the tropical tropopause. At T+72 and T+120 (Figures 5.17(a),(b)) the mean cooling at 150mb was 0.5C and the mean warming at 230mb was 0.4C.

At lower levels in the tropics, the temperature changes were more complex. Between 0-10N, the analysis (Figure 5.16(a)) showed a marked cooling of 0.3C centred on 800mb, which increased during the forecast to 0.7C by T+72 and T+120 (Figures 5.17(a),(b)). In the Southern Tropics,15S-25S, a low level cooling of 0.3C-0.5C centred on 950mb contrasts with a warming of 0.3C-0.5C at 650mb.

(ii) Zonal mean wind cross sections (Figures 5.18 - 5.20)

A comparison of the trial and operational zonal mean "u-component" cross sections shown in Figures 5.18 (a),(b) respectively show very little difference apart from a small increase in the trial easterly component at 150mb over the equator.

The operational zonal mean "v-component" cross sections at T+24 and T+120 (Figures 5.19b and 5.20b respectively), show the systematic model error in the upper branch of the Hadley Cell over the equator. In the operational cross section, the "v" wind component increases with forecast time from 3.5m/s at T+24 to 4.5m/s at T+120. In the corresponding trial cross sections (Figures 5.19a and 5.20a), the Hadley Cell is 0.5m/s weaker at each time. The southerly component near the surface at the equator is also slightly weaker in the trial cross sections.

(iii) Mean mean sea level pressure at T+120 (Figure 5.21-5.22)

The trial and operational T+120 mean mslp charts are compared in Figure 5.21 (a) and (b) respectively. The main features are almost identical but the difference chart, Figure 5.23, shows the tendency towards slightly deeper lows in the trial forecast, especially in the Southern Hemisphere.

(iv) Mean fraction of low cloud in the Northern Hemisphere

Figure 5.23 shows the difference (trial - operational) between the fractions of low layered cloud at T+36 in the Northern Hemisphere. The decrease is larger over the oceans, 0.3-0.5 at times, than over land.

(e) CONCLUSIONS

(i) Northern Hemisphere.

The assessment of slight evolution changes in mean sea level pressure and upper air forecasts at T+120 favoured the trial forecasts. The main impact of the "frozen physics package" in the Northern Hemisphere was seen in the increase of showers overland and the sharp reduction in low cloud especially over the sea. The increase in showers overland was mostly beneficial but the decrease in low cloud was overdone.

(ii) Tropics

The assessment of differences in trial and operational jets in the Southern Hemisphere tropics favoured the operational forecasts. The main impact of the "frozen physics package" in the tropics was seen in the increase in number of light/moderate showers in the ITCZ and overland in Asia. The trial forecast of showers overland was an improvement but areas of light showers were overdone.

(iii Southern Hemisphere.

The assessment of evolution changes in mean sea level pressure and upper air forecasts favoured the operational forecasts. Overall, the trial forecasts were slightly more cyclonic with slightly deeper lows and stronger jets.

References

Hammon, O and C Wilson 1993
Global forecast model trials of revised "frozen" physics - second and third parallel suite trials. Forecasting Research Technical Report no 76

Milton, S F 1993
Diagnosing systematic errors in the unified model - I-Thermal budget. Forecasting Research Technical Report no 64

Rawlins, F 1993
A comparison of objective verification methods for the global forecast model. Forecasting Research Working Paper no 157

Smith, R NB, D Gregory and J F B Mitchell 1993
Large-scale precipitation. Unified Model Documentation Paper no 26. Version 2.

Wilson, C 1993
Comparison of unified model cloud schemes 1A and 1B. Forecasting Research Working Paper no 152

Figure captions

2.1 Model levels, approximate pressures (1000η) hPa, cloud ranges for three cloud types in shortwave radiation.

3.1 Mean temperature bias profiles (Observed-model) at T+144 for December 1 week trial, for operational (full) and frozen (dashed) versions. a) northern hemisphere,b) tropics ,c) southern hemisphere, all with standard UM longwave radiation in frozen. d), e), f) as a), b) c) but with ECMWF-like transmissivities.

3.2 Mean temperature bias profiles (Observed-model) at T+144 for July 1 week trial, for operational (dashed) and frozen (full) versions. a) northern hemisphere,b) tropics ,c) southern hemisphere, all with standard UM longwave radiation in frozen. d), e), f) as a), b) c) but with ECMWF-like transmissivities.

3.3 Mean temperature bias profiles (Observed-model) at T+72 for December 1 week trial, for operational (full) and frozen (dashed) versions. As for fig 3.1

3.4 Mean temperature bias profiles (Observed-model) at T+72 for July 1 week trial, for operational (dashed) and frozen (full) versions. As for fig 3.2

3.5 Mean temperature bias profiles (Observed-model) for February 1 week trial, for operational (dashed) and frozen (full) versions. a) northern hemisphere,b) tropics ,c) southern hemisphere, at T+72. d), e), f) as a), b) c) but T+144. All frozen versions use ECMWF-like transmissivities.

3.6 Mean rms vector wind error profiles for December 1 week trial, verified against radiosondes and aireps for the northern hemisphere. a) T+24, b)T+72

3.7 Mean rms vector wind error profiles for December 1 week trial, verified against radiosondes and aireps for the tropics. a) T+24, b)T+72

3.8 Mean rms vector wind error profiles for December 1 week trial, verified against radiosondes and aireps for the southern hemisphere. a) T+24, b)T+72

3.9 Mean rms vector wind error profiles at T+72 for July 1 week trial, verified against radiosondes and aireps. a) northern hemisphere, b) tropics

3.10 Mean rms vector wind error profiles at T+72 for July 1 week trial, verified against radiosondes and aireps.; southern hemisphere

4.01 Mean bias and rms from verification against observations for temperature at T+120 plotted against pressure ; areas 2 and northern hemisphere; trial 1

4.02 Mean bias and rms from verification against observations for temperature at T+120 plotted against pressure ; tropics and southern hemisphere; trial 1

4.03 Mean bias and rms from verification against observations for height at T+120 plotted against pressure ; areas 2 and northern hemisphere; trial 1

4.04 Mean bias and rms from verification against observations for height at T+120 plotted against pressure ; tropics and southern hemisphere; trial 1

4.05 Mean bias and rms from verification against observations for winds at T+24 plotted against pressure ; areas 2 and northern hemisphere; trial 1

4.06 Mean bias and rms from verification against observations for winds at T+24 plotted against pressure ; tropics and southern hemisphere; trial 1

4.07 Mean bias and rms from verification against observations for winds at T+72 plotted against pressure ; areas 2 and northern hemisphere; trial 1

4.08 Mean bias and rms from verification against observations for winds at T+72 plotted against pressure ; tropics and southern hemisphere; trial 1

4.09 Mean bias and rms from verification against observations for relative humidity at T+120 plotted against pressure ; areas 2 and northern hemisphere; trial 1

4.10 Mean bias and rms from verification against observations for relative humidity at T+120 plotted against pressure ; tropics and southern hemisphere; trial 1
4.11 Mean bias and rms from verification against observations for surface pressure plotted against forecast period ; areas 2 and northern hemisphere; trial 1
4.12 Mean bias and rms from verification against observations for surface pressure plotted against forecast period ; tropics and southern hemisphere; trial 1
4.13 Mean bias and rms from verification against observations for surface temperature plotted against forecast period ; areas 2 and northern hemisphere; trial 1
4.14 Mean bias and rms from verification against observations for surface temperature plotted against forecast period ; tropics and southern hemisphere; trial 1

LIST OF FIGURES

5.01 Analysed U.K. Chart with observations for 12Z 12/06/93

5.02a,b T+24 hour forecasts from the trial(frozen physics package)and operational models respectively showing mean sea level pressure and rainfall rates,verifying at 12Z 12/06/93.

5.03a,b T+24 hour forecasts from the trial (frozen physics package) and operational models showing low and medium cloud ,verifying at 12Z 12/06/93. Charts show cloud greater than 4 octas.

5.04 Meteosat satellite visual image for 12Z 12/06/93 1993.

5.05a,b T+24 hour forecasts from the trial (frozen physics package) and operational models, showing low and medium cloud, verifying at 12Z 15/06/93. Charts show cloud greater than 4 octas.

5.06 Meteosat satellite visual image for 12Z 15/06/93.

5.07a,b Graphs showing the mean convective accumulation per grid square from the trial and operational model forecast in the Northern/Southern Hemisphere during the parallel suite trial 25/05/93 to 17/06/93.

5.08a,b As Figures 5.07a,b but for dynamic rain.

5.09 Graph showing the mean convective and dynamic accum per grid square from the trial and operational forecasts in the tropics during the parallel suite trial 25/05/93 to 17/06/93.

5.10a,b T+24 hour forecasts of mean sea level pressure and rainfall for the tropics (Africa,South America,Atlantic Ocean) from the trial and operational model, verifying at 12Z 11/06/93.

5.11a,b Meteosat satellite visual and infra red imagery valid 12Z 12/06/93

5.12a,b T+24 hour forecast of mean sea level pressure and rainfall for the tropics (Asia,Australia,South Pacific) from the trial and operational models respectively, verifying at 12Z 11/06/93.

5.13a,b T+120 hour forecasts of mean sea level pressure and rainfall for the South Atlantic Ocean and South America from the trial and operational models respectively, verifying at 12Z 07/06/93.

5.14 Operational analysis for the South Atlantic for 12Z 07/06/93.

5.15a,b T+120 hour forecasts from the trial and operational models respectively, showing 250mb wind isotachs for the South Atlantic, verifying at 12Z 07/06/93.

5.16a,b Zonal cross sections showing mean temperature differences between trial and operational forecasts at T+00 and T+24 respectively

5.17a,b Zonal cross sections showing mean temperature differences between trial and operational forecasts at T+72 and T+120 respectively.

5.18a,b Zonal "u wind component" cross sections at T+120 from the trial and operational forecasts respectively meaned over period 12Z 25/05/93 -12Z 17/06/93

5.19a,b Zonal "v wind component" cross sections at T+24 from the trial and operational forecasts respectively,meaned over the period 12Z 25/05/93 to 12Z 17/06/93

5.20a,b As 5.19(a),(b) but for T+120.

5.21a,b Mean mslp at T+120 for period 12Z 25/05/93 to 12Z 17/06/93 from trial and operational forecasts respectively.

5.22 Mean differences at T+120 (trial - operational) in mean sea level pressure 12Z 25/05/93 - 12Z 17/06/93

5.23 Mean differences at T+36 (trial - operational) in low cloud fraction

TEMPERATURE %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 2
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.2)	(3.2)	(6.4)	(8.7)	(9.5)	(5.8)
700	(2.8)	(2.0)	(3.5)	(4.5)	(4.9)	(1.3)
500	(0.5)	1.7	(2.8)	(4.1)	(4.1)	(1.5)
300	0.6	1.7	(0.1)	(1.9)	(2.7)	(3.7)
250	0.0	0.5	(1.3)	(3.7)	(1.1)	(0.8)
200	0.7	1.5	(1.3)	(3.2)	(2.2)	(0.3)
100	(0.5)	0.9	1.3	(0.8)	(1.8)	(0.7)
50	0.4	0.3	1.2	1.8	0.9	2.0

TEMPERATURE %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 200
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.9)	(3.2)	(4.8)	(5.4)	(6.6)	(6.5)
700	(1.4)	(1.6)	(1.9)	(2.7)	(2.8)	(3.2)
500	0.5	1.7	(0.1)	(1.8)	(2.9)	(2.1)
300	(0.3)	1.9	2.1	(0.2)	(2.2)	(1.8)
250	(0.2)	2.0	1.5	(0.2)	(1.1)	(1.7)
200	(0.1)	1.0	(0.5)	(1.0)	(1.1)	(1.0)
100	0.3	(0.3)	0.8	(1.5)	(3.0)	(3.9)
50	(0.3)	(0.4)	0.0	0.7	(0.3)	(0.2)

TEMPERATURE %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 300
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	0.5	2.6	0.9	(0.6)	0.3	(1.2)
700	3.0	3.6	2.2	0.8	0.5	(0.8)
500	(2.4)	(3.0)	(2.9)	(4.6)	(5.5)	(3.6)
300	1.0	1.0	2.5	(2.3)	(0.7)	(0.9)
250	0.7	3.9	4.8	3.3	2.6	2.1
200	1.5	5.0	6.8	7.0	8.3	9.5
100	(1.0)	(0.4)	0.8	1.6	1.3	1.7
50	(0.1)	0.5	0.1	0.5	1.2	1.5

TEMPERATURE %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 400
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	0.6	(1.7)	(2.3)	(1.7)	(2.9)	(1.3)
700	(1.1)	(0.5)	(2.0)	(1.8)	(2.8)	(1.1)
500	(1.4)	0.8	0.0	(0.2)	2.1	(2.0)
300	0.2	0.6	(0.7)	(1.2)	0.7	(1.6)
250	(0.6)	(0.8)	0.5	(1.1)	3.3	(1.8)
200	0.5	(2.5)	(2.3)	(1.3)	0.2	0.3
100	(0.1)	1.1	0.6	(0.2)	0.8	1.8
50	0.2	(1.1)	(0.7)	(2.1)	(1.3)	(0.5)

Table 4.1 Percentage change in rms for temperature from verification against observations from trial 1. Reductions in brackets.

TEMP RMSE %CHANGE (TRIAL-OPERATIONAL)
AREA 2
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(5.4)	(8.0)	(8.8)	(7.7)	(4.8)
700	(3.2)	(2.6)	(3.9)	(4.5)	(2.2)
500	(2.3)	(2.0)	(2.9)	(6.3)	(1.6)
300	0.0	(1.7)	0.0	(2.3)	(0.3)
250	(0.7)	(1.9)	(3.0)	(2.5)	0.5
200	(1.5)	(2.8)	(3.8)	(1.9)	(0.5)
100	0.0	1.1	0.0	(4.4)	(2.1)
50	0.0	1.0	1.6	(0.7)	0.6

TEMP RMSE %CHANGE (TRIAL-OPERATIONAL)
N.HEM
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(4.1)	(5.4)	(5.0)	(4.1)	(4.7)
700	0.0	(1.4)	(2.0)	(2.5)	(3.2)
500	1.2	(0.7)	(1.0)	(2.9)	(2.5)
300	1.7	2.3	1.9	(0.4)	(0.7)
250	2.3	1.6	0.4	(0.7)	(0.9)
200	0.0	0.0	(0.8)	(0.3)	(1.6)
100	0.0	0.9	0.7	(1.7)	(3.3)
50	(1.3)	0.0	(0.7)	(3.4)	(2.0)

TEMP RMSE %CHANGE (TRIAL-OPERATIONAL)
TROPICS
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(1.3)	(0.9)	(0.7)	0.0	(4.7)
700	(1.3)	(1.6)	(1.8)	(1.1)	(3.2)
500	(3.3)	(4.2)	(5.7)	(4.1)	(2.5)
300	0.0	1.0	0.0	0.0	(0.7)
250	2.5	3.5	3.0	4.0	(0.9)
200	7.8	8.9	11.2	9.9	(1.6)
100	0.0	1.0	0.8	(0.7)	(3.3)
50	0.0	(2.1)	(0.9)	(3.8)	(2.0)

TEMP RMSE %CHANGE (TRIAL-OPERATIONAL)
S.HEM
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(1.2)	(2.4)	(2.5)	0.0	(4.7)
700	(1.2)	(3.1)	(3.3)	(2.0)	(3.2)
500	(2.2)	(1.7)	0.0	0.3	(2.5)
300	0.0	0.0	0.4	1.1	(0.7)
250	0.7	0.0	0.0	1.3	(0.9)
200	(1.4)	(0.4)	1.7	3.0	(1.6)
100	0.0	0.7	2.9	1.8	(3.3)
50	(1.1)	0.0	0.0	1.6	(2.0)

Table 4.2 Percentage change in rms for temperature from verification against analyses from trial 1. Reductions in brackets.

HEIGHT %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 2
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	0.0	(1.7)	(1.5)	(2.1)	(1.0)	(1.1)
700	0.0	(1.3)	(2.5)	(3.7)	(2.5)	(0.7)
500	0.7	(0.7)	(3.2)	(5.3)	(3.2)	(1.1)
300	0.7	1.0	(3.4)	(5.9)	(4.4)	(2.0)
250	0.7	1.3	(2.7)	(5.9)	(4.9)	(2.3)
200	0.4	1.1	(2.6)	(5.8)	(5.5)	(3.0)
100	0.2	0.3	(2.3)	(5.0)	(5.6)	(4.2)
50	0.0	0.2	(1.3)	(2.8)	(3.3)	(4.3)

HEIGHT %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 200
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.3)	(3.5)	(0.8)	(0.3)	0.8	0.2
700	(0.1)	(3.0)	(2.1)	(2.3)	(1.2)	(1.0)
500	0.2	(1.2)	(1.3)	(2.9)	(2.8)	(2.3)
300	0.5	1.5	0.0	(2.6)	(3.9)	(3.2)
250	0.4	2.2	0.8	(2.3)	(4.2)	(3.3)
200	0.4	2.2	1.4	(1.8)	(4.6)	(3.8)
100	0.6	0.8	0.0	(1.2)	(4.1)	(5.5)
50	0.1	(0.2)	(1.6)	(2.5)	(4.3)	(5.4)

HEIGHT %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 300
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.6)	(4.0)	(4.9)	(2.7)	(1.2)	2.2
700	(2.0)	0.7	(0.2)	1.2	(0.6)	2.7
500	(0.1)	(0.6)	(0.4)	(1.3)	(0.9)	(0.9)
300	0.4	(1.1)	(0.3)	(1.4)	(1.3)	(1.1)
250	(0.6)	(0.6)	0.7	(2.3)	(2.6)	(2.1)
200	1.4	1.6	2.7	1.0	0.0	0.1
100	0.9	(1.1)	(1.0)	(1.4)	(3.6)	(4.3)
50	(0.2)	(0.4)	(0.9)	(1.8)	(3.6)	(5.1)

HEIGHT %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 400
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(1.3)	(0.2)	(1.1)	(1.2)	1.8	0.9
700	(2.1)	0.0	(0.1)	(0.7)	1.9	0.3
500	0.6	(0.3)	(1.2)	(0.8)	1.2	(0.2)
300	(0.3)	(0.8)	(2.1)	(1.5)	0.0	(0.4)
250	(0.3)	(0.6)	(2.0)	(2.0)	(0.4)	0.0
200	0.5	(1.1)	(1.4)	(2.7)	(1.3)	(0.1)
100	0.9	(0.4)	(2.3)	(2.9)	(3.4)	(1.3)
50	0.8	(0.9)	(2.1)	(2.4)	(2.9)	(3.4)

Table 4.3 Percentage change in rms for height from verification against observations from trial 1. Reductions in brackets.

HEIGHT RMSE %CHANGE (TRIAL-OPERATIONAL)
AREA 2
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(1.7)	(1.0)	(1.4)	1.3	2.6
700	(1.6)	(2.3)	(3.5)	(0.5)	1.4
500	(1.3)	(2.5)	(3.8)	(2.7)	0.0
300	(2.2)	(2.8)	(4.1)	(4.6)	(1.4)
250	(1.7)	(3.0)	(4.3)	(4.9)	(2.0)
200	(2.2)	(4.7)	(5.2)	(6.0)	(3.0)
100	(5.1)	(7.7)	(8.5)	(9.6)	(6.9)
50	(3.8)	(5.4)	(7.4)	(10.7)	(8.8)

HEIGHT RMSE %CHANGE (TRIAL-OPERATIONAL)
N.HEM
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(0.8)	(1.0)	0.4	0.9	1.6
700	(1.7)	(1.4)	(0.7)	0.0	0.4
500	(0.7)	(0.8)	(1.1)	(1.2)	(1.1)
300	1.0	0.3	(1.1)	(2.3)	(2.6)
250	1.3	0.8	(1.1)	(2.6)	(3.1)
200	0.9	0.3	(1.2)	(3.5)	(4.5)
100	(1.0)	(2.6)	(3.7)	(8.3)	(10.0)
50	(2.4)	(4.0)	(5.2)	(8.6)	(9.3)

HEIGHT RMSE %CHANGE (TRIAL-OPERATIONAL)
TROPICS
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(5.5)	(3.4)	0.8	0.0	4.8
700	(2.5)	(1.8)	1.6	(1.4)	1.9
500	(3.5)	(4.9)	(2.6)	(2.3)	0.0
300	(0.9)	(1.8)	(2.3)	(3.1)	(2.3)
250	0.8	(1.1)	(1.6)	(2.7)	(2.6)
200	2.1	0.9	0.7	(0.6)	(1.0)
100	(1.6)	(3.8)	(4.3)	(5.7)	(6.3)
50	(0.9)	(3.9)	(5.2)	(8.5)	(9.0)

HEIGHT RMSE %CHANGE (TRIAL-OPERATIONAL)
S.HEM
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(0.4)	(0.5)	0.6	2.6	3.5
700	(0.9)	(1.4)	0.4	2.7	2.8
500	(1.2)	(2.2)	(0.3)	1.9	1.6
300	(2.4)	(2.6)	(0.9)	1.1	0.6
250	(2.7)	(2.8)	(1.3)	0.8	0.4
200	(2.9)	(3.3)	(2.2)	(0.3)	(0.4)
100	(3.4)	(4.8)	(4.8)	(3.5)	(3.2)
50	(4.3)	(5.1)	(4.0)	(3.2)	(3.3)

Table 4.4 Percentage change in rms for height from verification against analyses from trial 1. Reductions in brackets.

WIND %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 2
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.2)	(1.9)	(0.8)	(1.5)	(1.0)	0.5
700	(0.2)	(1.2)	(0.9)	(1.8)	(2.1)	(0.4)
500	0.3	(0.3)	(1.0)	(1.5)	(2.1)	(0.5)
400	0.1	0.3	(1.3)	(1.5)	(2.0)	(0.8)
300	(0.5)	(0.3)	(1.6)	(1.2)	(1.4)	(0.3)
250	(0.1)	(0.3)	(0.8)	(1.1)	(1.4)	0.0
200	(0.2)	0.0	(0.1)	(0.2)	(2.3)	(0.7)
100	(0.2)	0.0	(0.8)	0.0	(1.4)	(0.4)

WIND %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 200
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.1)	(1.2)	(0.5)	(0.3)	0.0	0.5
700	0.0	(0.2)	(0.4)	(0.6)	(1.4)	(0.2)
500	(0.1)	0.0	0.0	(1.1)	(1.1)	(0.7)
400	0.0	(0.1)	0.0	(1.1)	(1.0)	(1.0)
300	(0.2)	0.2	0.2	(0.7)	(0.8)	(0.8)
250	(0.3)	0.1	0.8	(0.8)	(0.8)	(0.7)
200	0.1	1.4	1.5	(1.3)	(1.7)	(1.5)
100	0.4	(0.4)	0.1	(0.8)	(1.4)	(2.9)

WIND %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 300
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.7)	(1.3)	(2.1)	(1.2)	(0.2)	3.0
700	(0.6)	(1.4)	0.6	(0.2)	1.0	2.5
500	0.2	0.9	2.6	0.6	0.9	1.6
400	0.0	0.8	2.4	0.3	1.1	0.1
300	(1.1)	(0.7)	1.0	(0.7)	0.7	(0.8)
250	0.0	(0.1)	(0.2)	(0.1)	1.1	(1.2)
200	0.4	0.2	0.9	(0.2)	0.9	0.0
100	(0.4)	0.4	0.7	0.1	0.3	(1.1)

WIND %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 400
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.6)	(0.6)	0.2	0.1	0.4	(0.8)
700	1.0	0.6	0.6	1.2	1.1	1.1
500	(1.4)	1.6	0.1	2.6	1.6	1.3
400	1.3	0.7	1.0	3.4	3.4	4.1
300	(1.2)	(1.4)	(0.1)	1.6	1.2	3.2
250	0.8	0.3	0.4	1.8	0.7	3.0
200	1.7	1.0	0.7	1.1	1.0	2.4
100	0.1	(0.9)	0.1	(1.0)	0.2	0.4

Table 4.5 Percentage change in rms for winds from verification against observations from trial 1. Reductions in brackets

WIND RMSVW %CHANGE (TRIAL-OPERATIONAL)
AREA 2
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(0.5)	0.2	(0.5)	(0.4)	2.8
700	(0.4)	(0.5)	(1.3)	(1.2)	2.0
500	(0.6)	(0.4)	(1.6)	(1.6)	0.8
300	0.4	0.4	(0.9)	(0.7)	0.7
250	0.2	0.8	(0.3)	(0.2)	0.7
200	0.6	(0.3)	0.3	(0.9)	0.3
100	(0.2)	(1.0)	(0.7)	(3.9)	(1.1)

WIND RMSVW %CHANGE (TRIAL-OPERATIONAL)
N HEM
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(0.4)	0.4	0.7	0.7	1.5
700	(0.4)	(0.4)	0.0	(0.1)	0.6
500	(0.1)	0.1	0.1	(0.4)	(0.3)
300	0.7	1.2	1.0	0.8	(0.1)
250	0.3	1.3	0.8	0.8	(0.6)
200	1.0	0.9	0.7	(0.1)	(1.7)
100	0.4	0.3	0.3	(1.0)	(2.4)

WIND RMSVW %CHANGE (TRIAL-OPERATIONAL)
TROPICS
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(1.8)	(1.0)	0.7	1.8	2.6
700	0.0	(0.7)	0.0	0.4	0.3
500	(0.4)	(1.4)	(0.3)	0.4	0.7
300	(0.7)	(0.7)	0.5	0.3	1.3
250	(0.7)	(0.7)	(0.1)	(0.2)	0.3
200	(1.2)	(1.3)	(1.0)	(0.4)	0.0
100	0.3	(0.2)	0.4	0.8	0.5

WIND RMSVW %CHANGE (TRIAL-OPERATIONAL)
S.HEM
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
850	(0.1)	0.0	0.9	2.3	1.7
700	0.0	(0.5)	1.0	2.3	1.6
500	0.1	(0.1)	1.3	2.4	1.4
300	(0.2)	0.0	1.6	3.5	2.2
250	(0.3)	(0.1)	1.6	3.9	2.9
200	0.0	(0.2)	2.0	3.8	3.5
100	(0.5)	(1.2)	(0.3)	1.7	2.3

Table 4.6 Percentage change in rms for winds from verification against analyses from trial 1. Reductions in brackets.

REL HUM %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 2
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.3)	(0.4)	(2.2)	(2.6)	(2.1)	(3.0)
700	(1.5)	(4.2)	(2.3)	(2.5)	(3.0)	(3.6)
500	(0.6)	(0.8)	(0.8)	(1.7)	0.0	(1.0)

REL HUM %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 200
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	(0.1)	(0.6)	(0.9)	(1.2)	(1.4)	(1.4)
700	(1.0)	(2.6)	(0.8)	(0.9)	(1.1)	(1.1)
500	(0.4)	(0.7)	(0.7)	(0.8)	0.3	(0.8)

REL HUM %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 300
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	0.3	(0.6)	(0.7)	(0.4)	(0.9)	(1.2)
700	(1.0)	1.4	0.0	(0.4)	0.3	(1.6)
500	0.0	(1.4)	(0.1)	(2.2)	(2.4)	0.5

REL HUM %RMS CHANGE (TRIAL-OPERATIONAL)
STATISTICS FOR AREA 400
VERIFICATION AGAINST OBSERVATIONS

	T+0	T+24	T+48	T+72	T+96	T+120
850	0.5	0.3	(2.7)	(0.2)	(1.6)	(2.8)
700	0.9	(1.9)	(1.4)	(1.2)	(0.2)	(3.1)
500	0.6	(0.4)	(1.1)	(0.5)	(1.4)	4.6

Table 4.7 Percentage change in rms for relative humidity from verification against observations from trial 1. Reductions in brackets.

RELHUM RMSE %CHANGE (TRIAL-OPERATIONAL)
AREA 2
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
950	(3.5)	(6.5)	(7.4)	(8.3)	(5.3)
850	(2.4)	(2.7)	(2.5)	(2.4)	(1.4)
700	(4.1)	(3.0)	(3.4)	(1.6)	(1.1)
500	(2.1)	(1.1)	(2.0)	(1.2)	(1.1)

RELHUM RMSE %CHANGE (TRIAL-OPERATIONAL)
N HEM
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
950	(1.3)	(2.8)	(3.2)	(2.8)	(3.1)
850	(1.1)	(1.3)	(1.3)	(1.0)	(1.8)
700	(2.3)	(1.5)	(1.6)	(1.1)	(1.4)
500	(1.8)	(1.4)	(1.4)	(1.1)	(1.1)

RELHUM RMSE %CHANGE (TRIAL-OPERATIONAL)
TROPICS
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
950	6.0	5.3	5.1	3.3	3.5
850	5.2	7.1	7.5	8.0	7.5
700	(0.1)	(0.6)	0.5	0.2	0.8
500	(3.6)	(4.2)	(3.7)	(4.1)	(3.7)

RELHUM RMSE %CHANGE (TRIAL-OPERATIONAL)
S.HEM
VERIFICATION AGAINST ANALYSES

	T+24	T+48	T+72	T+96	T+120
950	(1.2)	(5.1)	(4.2)	(3.1)	(4.6)
850	(0.8)	(2.4)	(2.0)	(0.4)	(1.3)
700	(3.6)	(2.5)	(2.2)	(1.6)	(1.8)
500	(1.5)	(0.8)	(0.5)	0.1	(0.3)

Table 4.8 Percentage change in rms for relative humidity from verification against analyses from trial 1. Reductions in brackets.

Table 4.9 Count of cases in which trial rms is better than or equal to the operational rms from verification against observations and against analyses from trial 1.

RMS RATIO (TRIAL/OPERATIONAL) ≤ 100%
FOR ALL TIMES AND ALL LEVELS
VERIFICATION AGAINST OBSERVATIONS

	TEMP max=48	HEIGHT max=48	WIND max=48	REL HUM max=18
AREA 2	34	38	44	18
N HEM	38	32	38	17
TROPICS	15	35	22	14
S HEM	32	38	9	13

max=no.times x no. levels

RMS RATIO (TRIAL/OPERATIONAL) ≤ 100%
FOR ALL TIMES AND ALL LEVELS
VERIFICATION AGAINST ANALYSES

	TEMP max=40	HEIGHT max=40	WIND max=35	REL HUM max=20
AREA 2	35	37	22	20
N HEM	31	30	14	20
TROPICS	29	32	20	7
S HEM	30	28	14	19

max=no.times x no. levels

UNIFIED MODEL
19 LEVELS

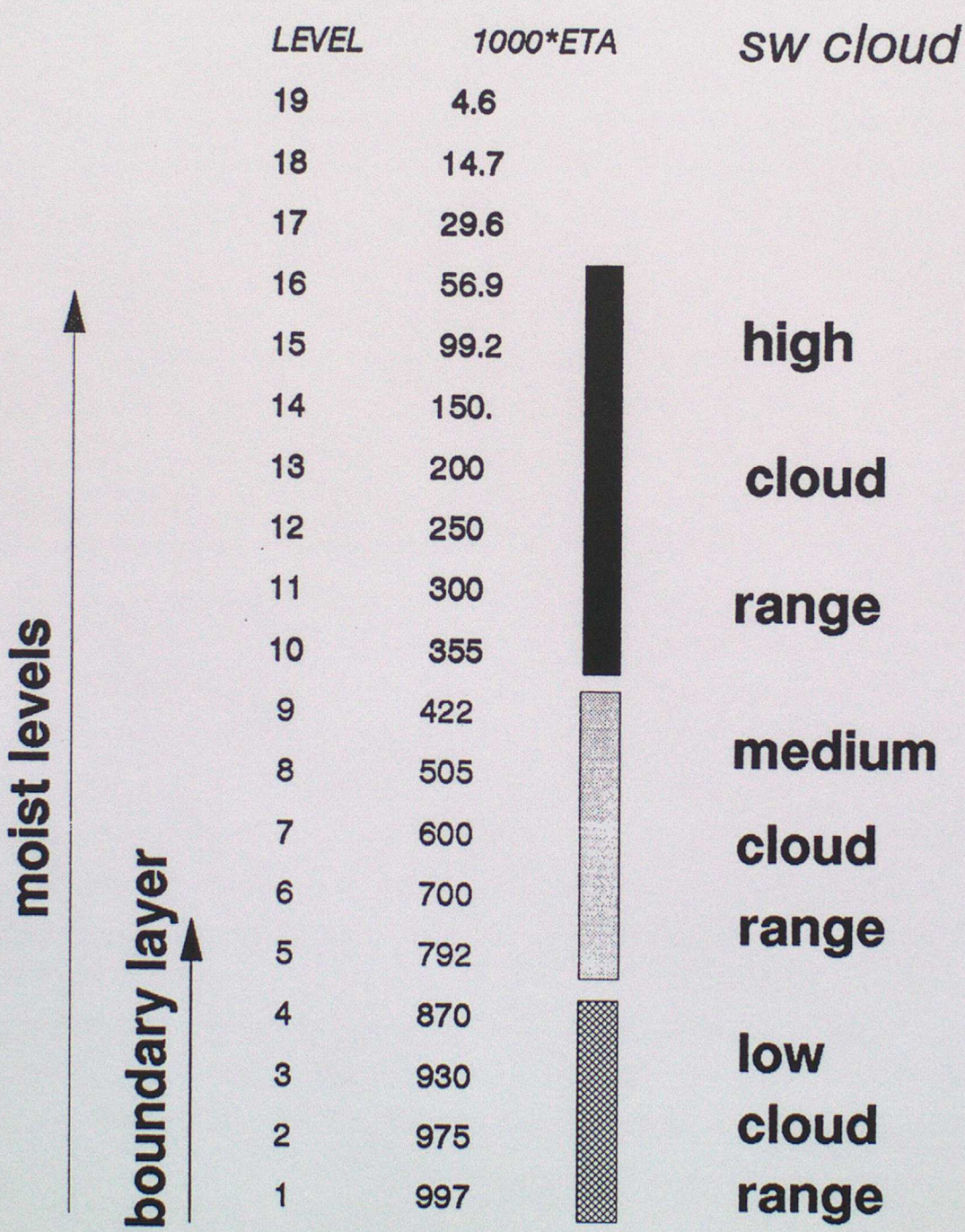


Fig 2.1

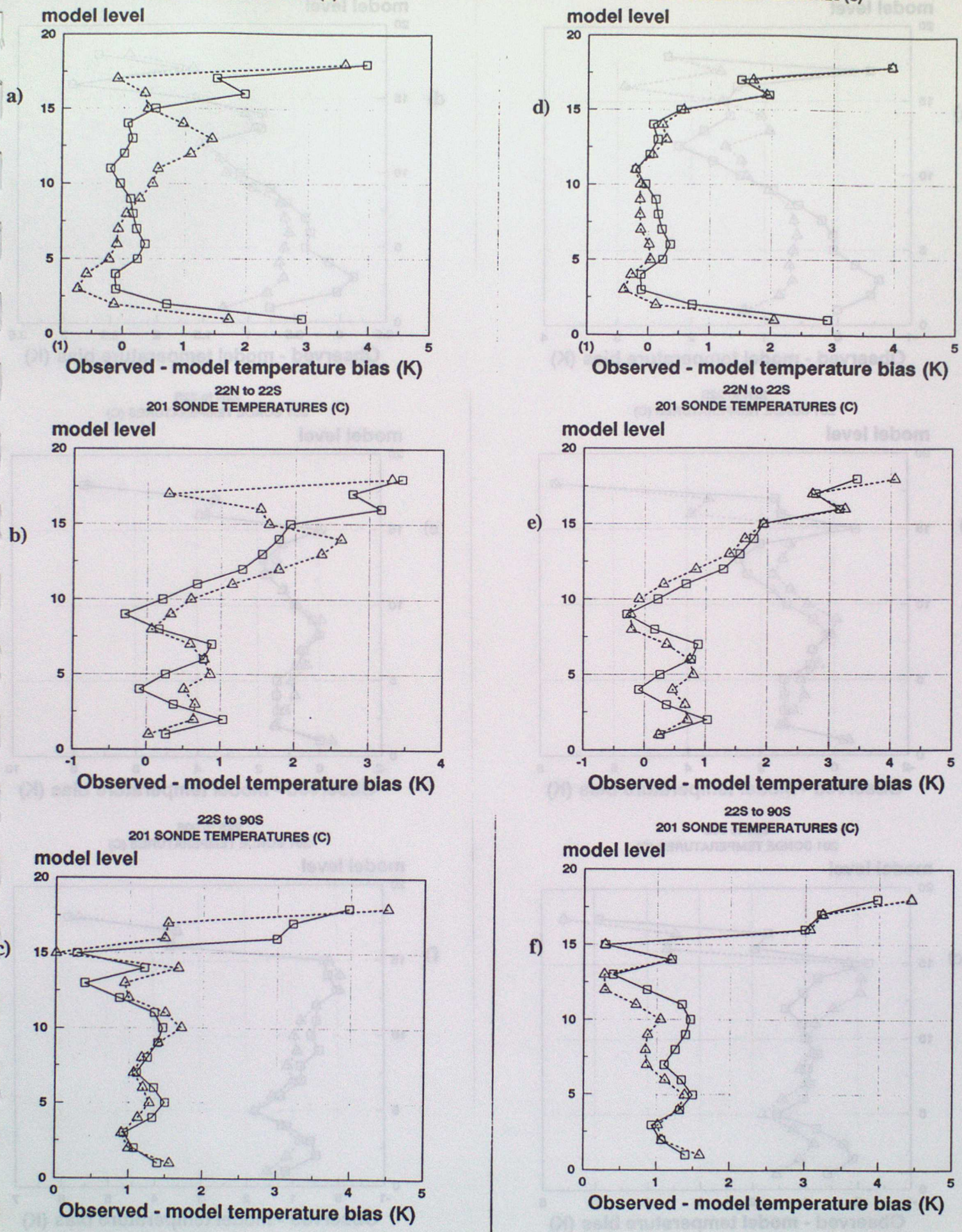

SBTE vn3.1 11/12/92 TO 17/12/92 T+144
90N to 22N
201 SONDE TEMPERATURES (C)
model level
a)
Observed - model temperature bias (K)
22N to 22S
201 SONDE TEMPERATURES (C)
model level
b)
Observed - model temperature bias (K)
22S to 90S
201 SONDE TEMPERATURES (C)
model level
c)
Observed - model temperature bias (K)
SBTE vn3.1 11/12/92 TO 17/12/92 T+144
90N to 22N
201 SONDE TEMPERATURES (C)
model level
d)
Observed - model temperature bias (K)
22N to 22S
201 SONDE TEMPERATURES (C)
model level
e)
Observed - model temperature bias (K)
22S to 90S
201 SONDE TEMPERATURES (C)
model level
f)
Observed - model temperature bias (K)
CONTROL
FROZEN
FROZEN2
Continuous assimilation cycle started
6 hours before initial date

Fig 3.1

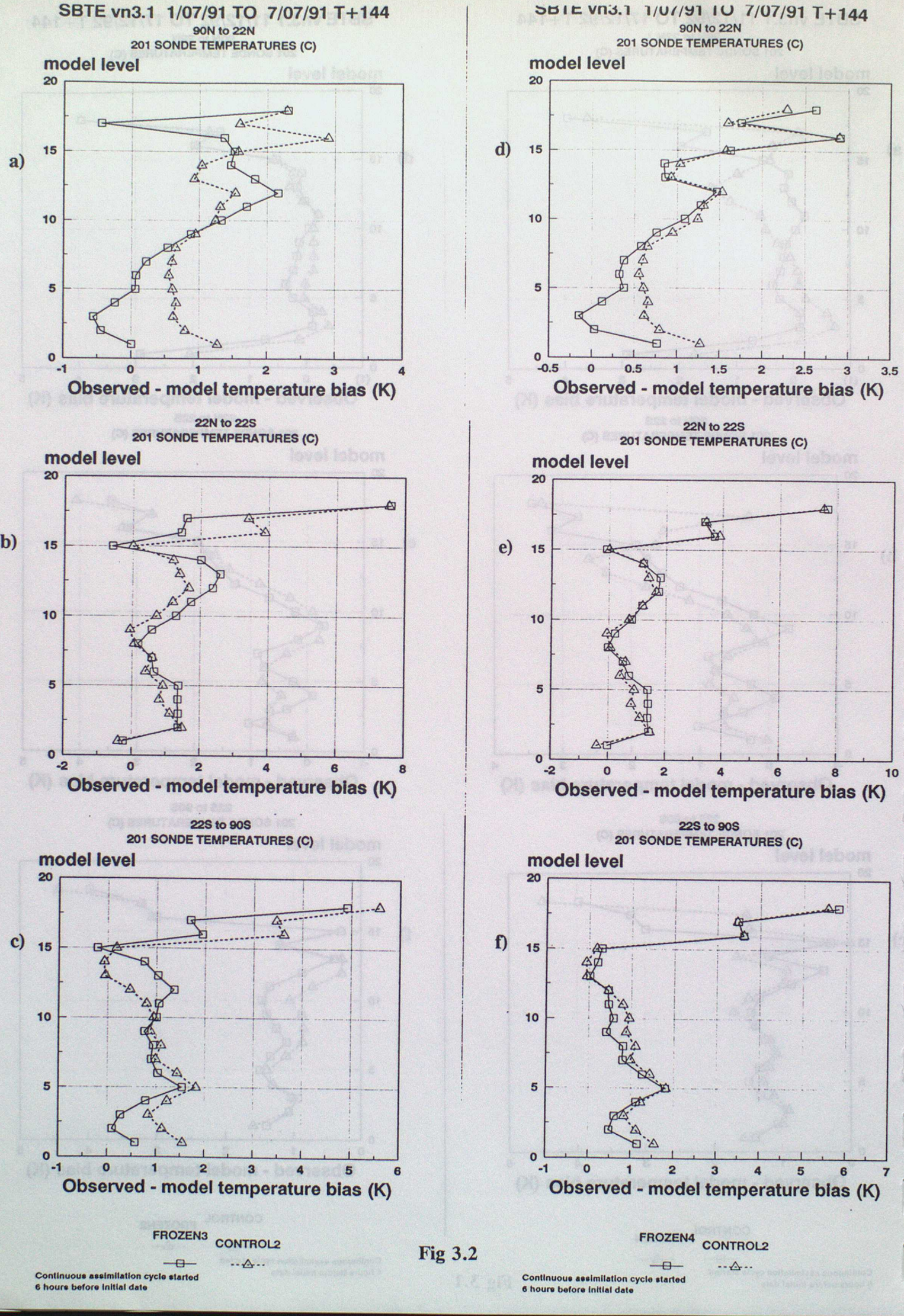
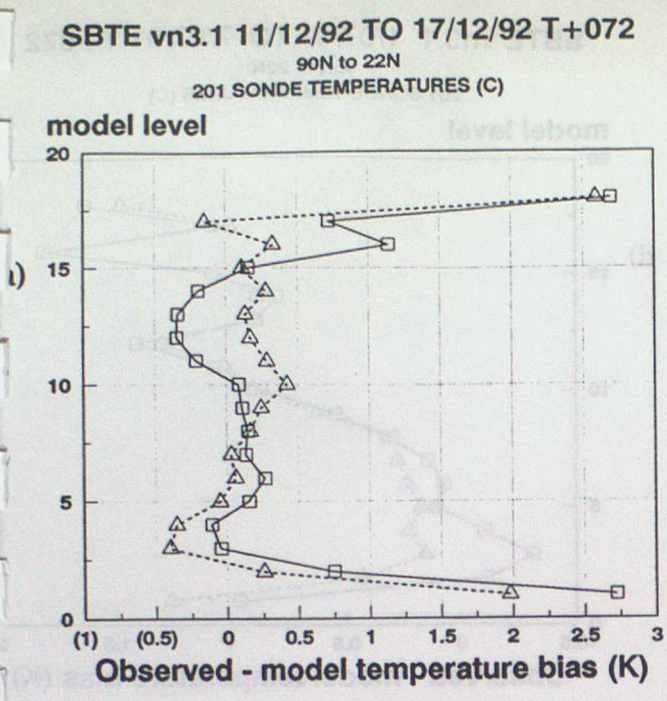
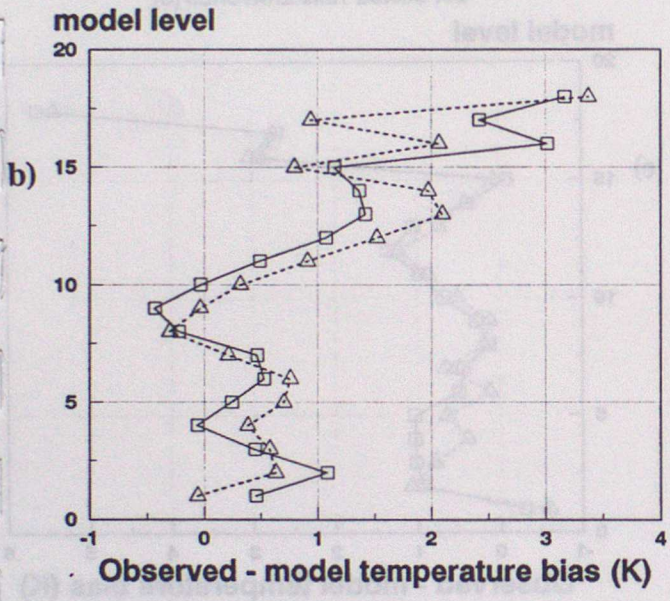
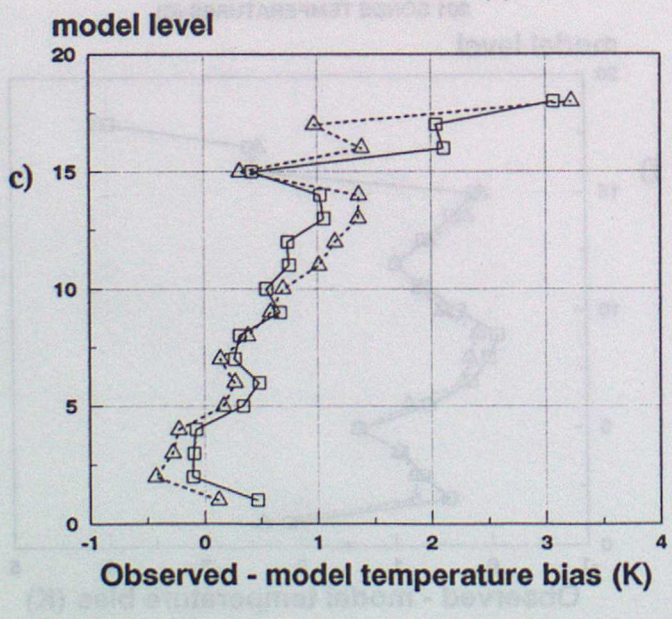
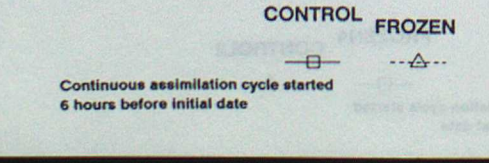

SBTE vn3.1 1/07/91 TO 7/07/91 T+144
90N to 22N
201 SONDE TEMPERATURES (C)
model level
a)
Observed - model temperature bias (K)
22N to 22S
201 SONDE TEMPERATURES (C)
model level
b)
Observed - model temperature bias (K)
22S to 90S
201 SONDE TEMPERATURES (C)
model level
c)
Observed - model temperature bias (K)
SBTE vn3.1 1/07/91 TO 7/07/91 T+144
90N to 22N
201 SONDE TEMPERATURES (C)
model level
d)
Observed - model temperature bias (K)
22N to 22S
201 SONDE TEMPERATURES (C)
model level
e)
Observed - model temperature bias (K)
22S to 90S
201 SONDE TEMPERATURES (C)
model level
f)
Observed - model temperature bias (K)
FROZEN3
CONTROL2
Continuous assimilation cycle started
6 hours before initial date
FROZEN4
CONTROL2
Continuous assimilation cycle started
6 hours before initial date

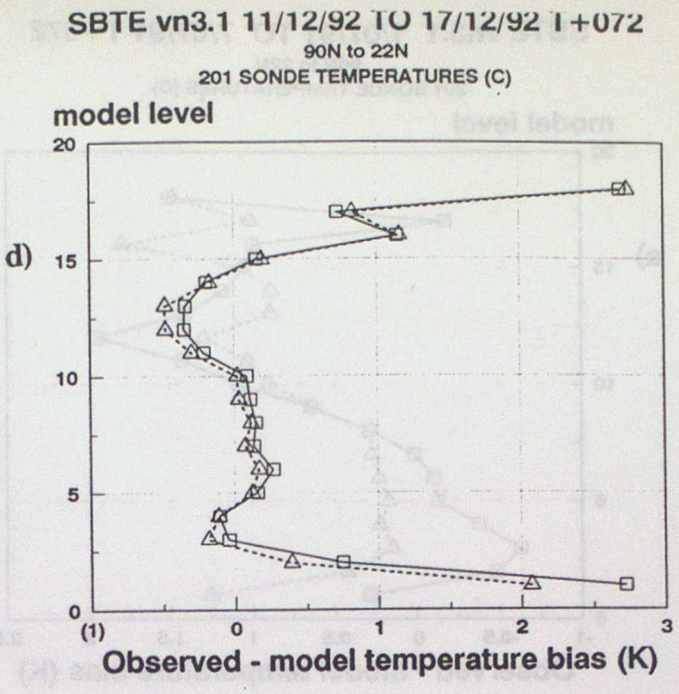
Fig 3.2

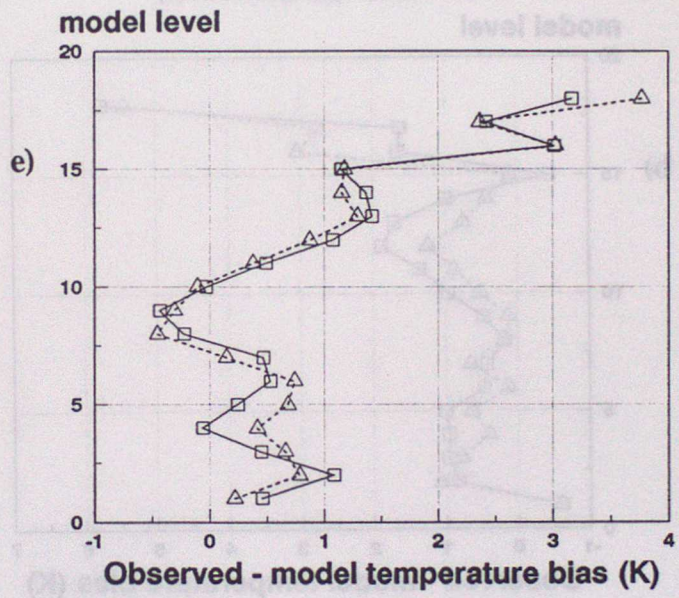

SBTE vn3.1 11/12/92 TO 17/12/92 T+072
90N to 22N
201 SONDE TEMPERATURES (C)
model level
a)
Observed - model temperature bias (K)

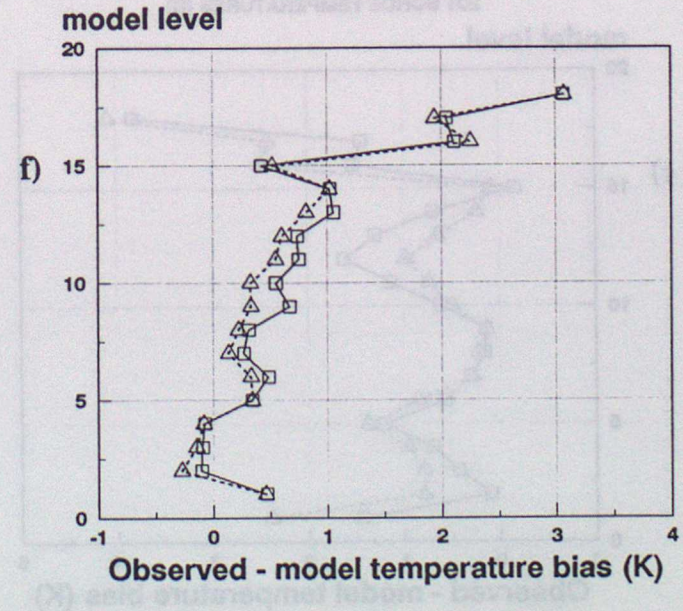

22N to 22S
201 SONDE TEMPERATURES (C)
model level
b)
Observed - model temperature bias (K)


22S to 90S
201 SONDE TEMPERATURES (C)
model level
c)
Observed - model temperature bias (K)


CONTROL
FROZEN
Continuous assimilation cycle started
6 hours before initial date


SBTE vn3.1 11/12/92 TO 17/12/92 T+072
90N to 22N
201 SONDE TEMPERATURES (C)
model level
d)
Observed - model temperature bias (K)


22N to 22S
201 SONDE TEMPERATURES (C)
model level
e)
Observed - model temperature bias (K)


22S to 90S
201 SONDE TEMPERATURES (C)
model level
f)
Observed - model temperature bias (K)

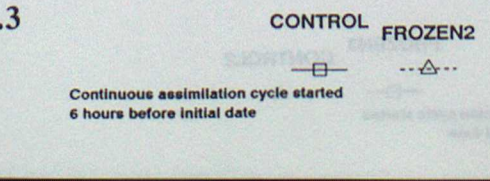

CONTROL
FROZEN2
Continuous assimilation cycle started
6 hours before initial date

Fig 3.3

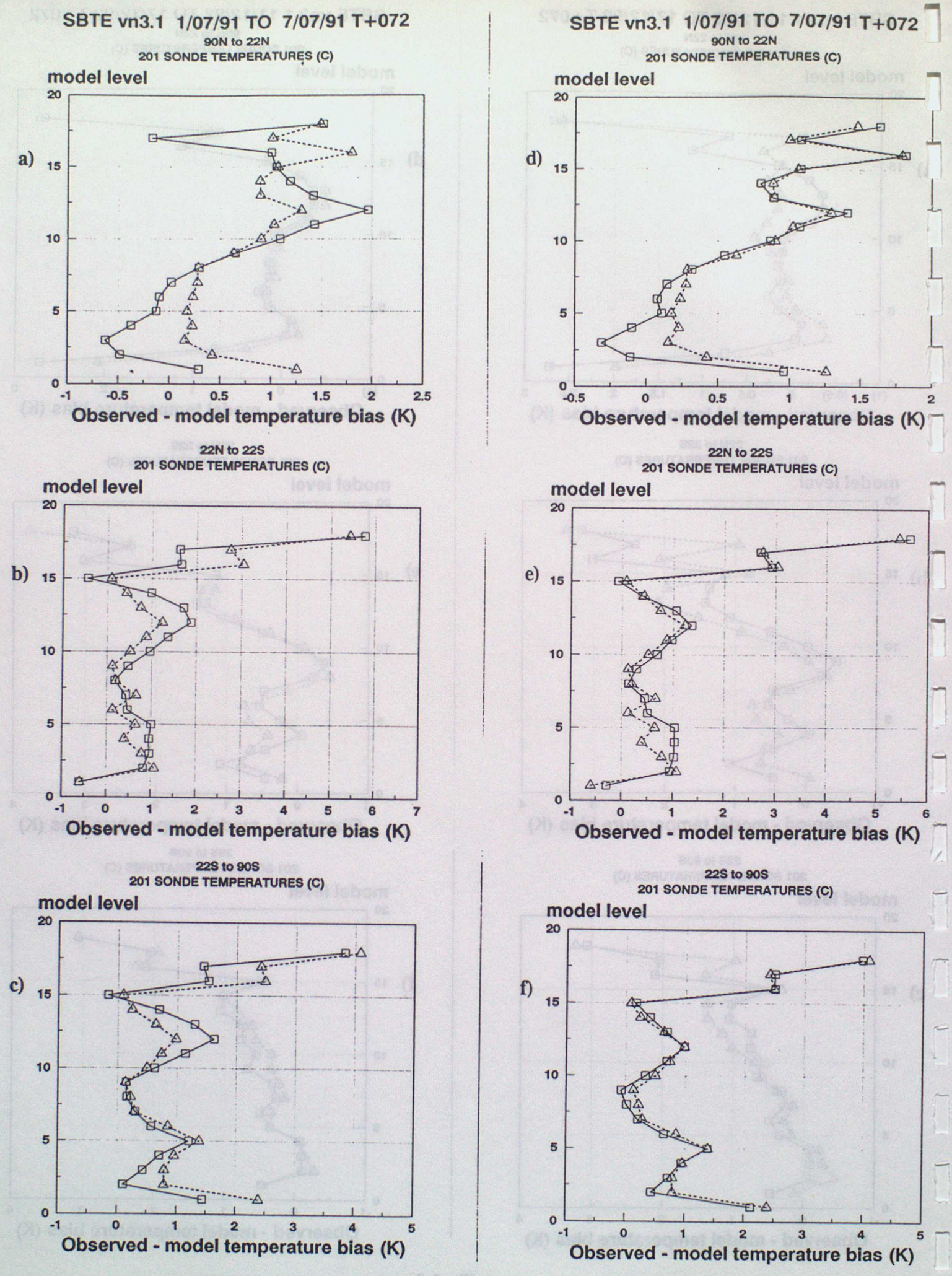

SBTE vn3.1 1/07/91 TO 7/07/91 T+072
90N to 22N
201 SONDE TEMPERATURES (C)
model level
a)
Observed - model temperature bias (K)
SBTE vn3.1 1/07/91 TO 7/07/91 T+072
90N to 22N
201 SONDE TEMPERATURES (C)
model level
d)
Observed - model temperature bias (K)
22N to 22S
201 SONDE TEMPERATURES (C)
model level
b)
Observed - model temperature bias (K)
22N to 22S
201 SONDE TEMPERATURES (C)
model level
e)
Observed - model temperature bias (K)
22S to 90S
201 SONDE TEMPERATURES (C)
model level
c)
Observed - model temperature bias (K)
22S to 90S
201 SONDE TEMPERATURES (C)
model level
f)
Observed - model temperature bias (K)
FROZEN3
CONTROL2
Continuous assimilation cycle started
6 hours before initial date
FROZEN4
CONTROL2
Continuous assimilation cycle started
6 hours before initial date

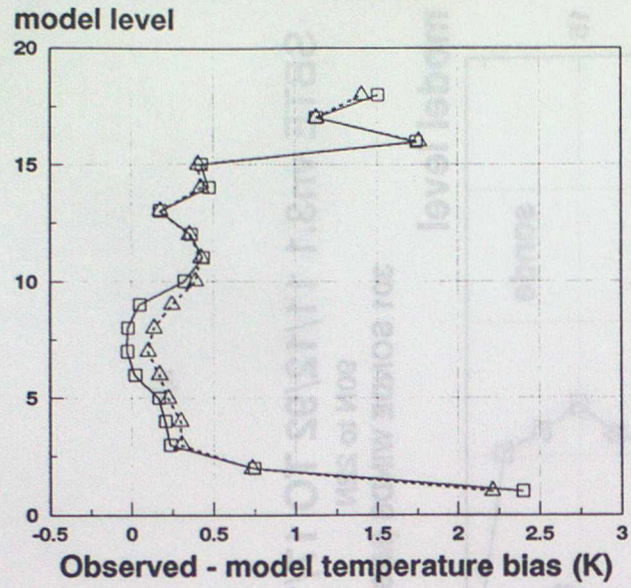
Fig 3.4

SBTE vn3.1 30/01/93 TO 5/02/93 T+072

90N to 22N

201 SONDE TEMPERATURES (C)

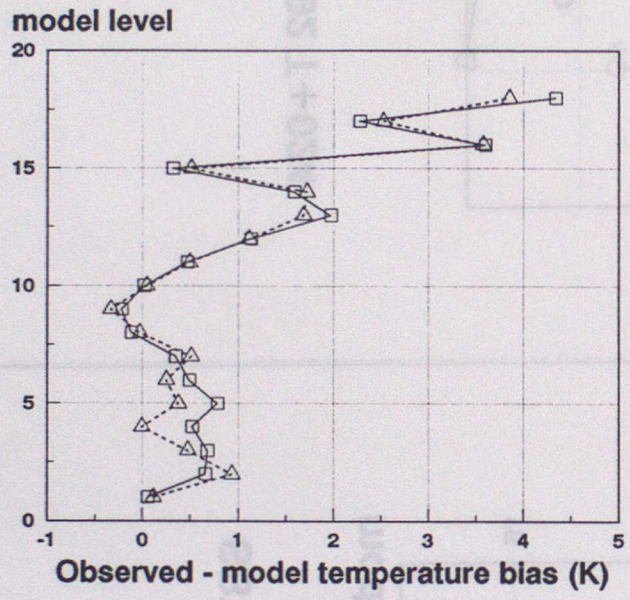
a)



22N to 22S

201 SONDE TEMPERATURES (C)

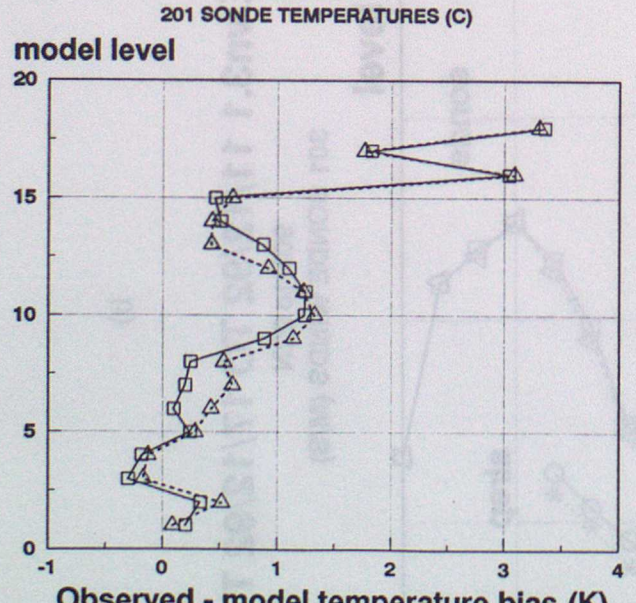
b)



22S to 90S

201 SONDE TEMPERATURES (C)

c)



FROZEN4 CONTROL

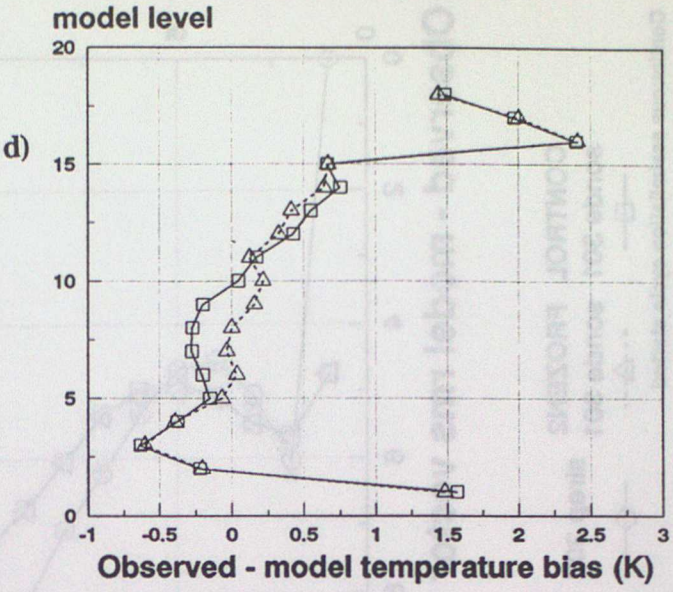
Continuous assimilation cycle started 6 hours before initial date

SBTE vn3.1 30/01/93 TO 5/02/93 T+144

90N to 22N

201 SONDE TEMPERATURES (C)

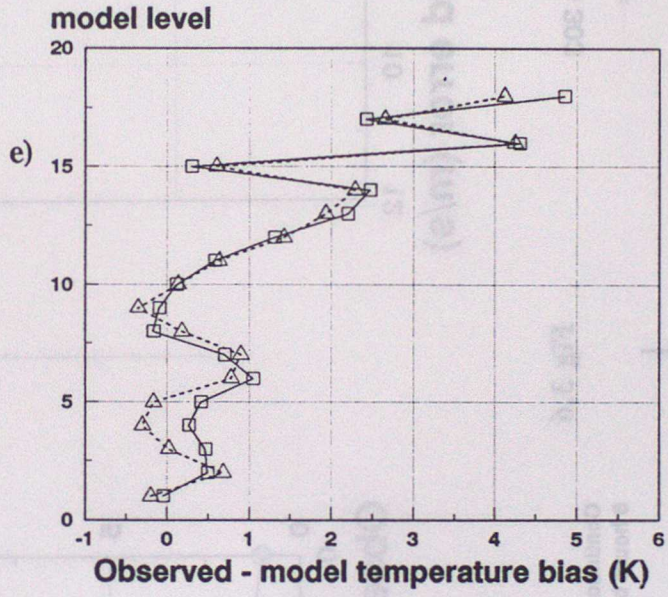
d)



22N to 22S

201 SONDE TEMPERATURES (C)

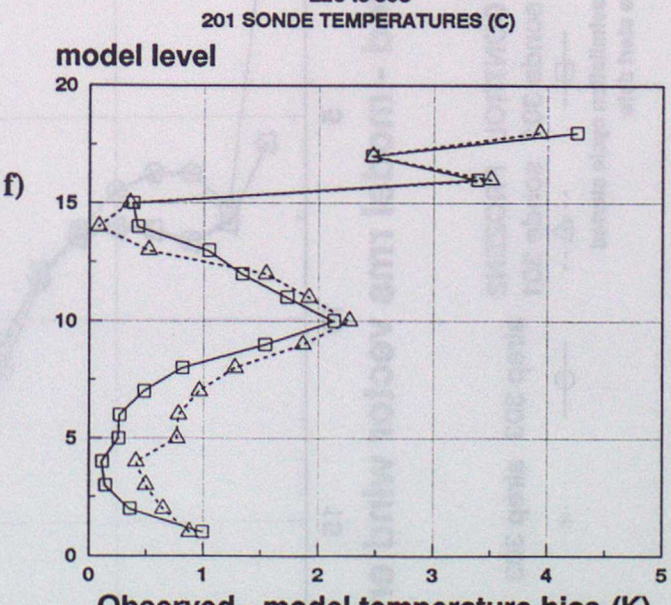
e)



22S to 90S

201 SONDE TEMPERATURES (C)

f)

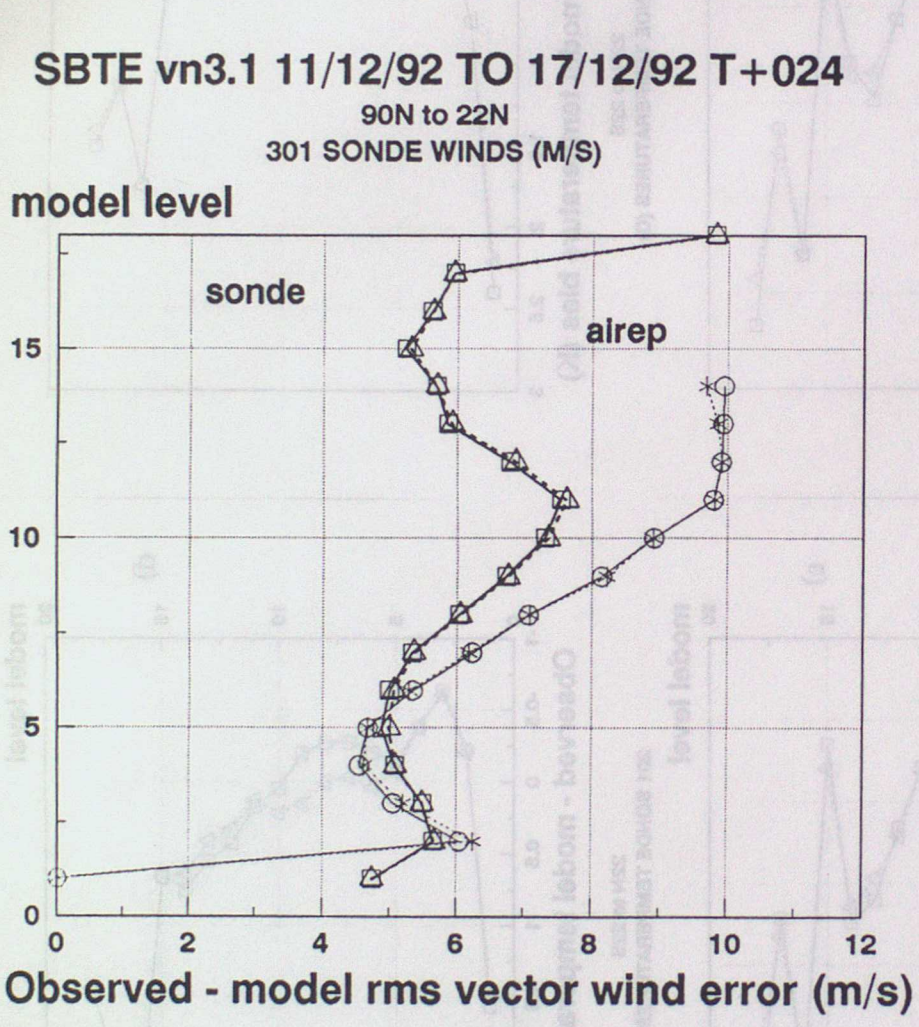


FROZEN4 CONTROL

Continuous assimilation cycle started 6 hours before initial date

Fig 3.5

a)


SBTE vn3.1 11/12/92 TO 17/12/92 T+024
90N to 22N
301 SONDE WINDS (M/S)
model level
sonde
airep
0
5
10
15
0
2
4
6
8
10
12
Observed - model rms vector wind error (m/s)
CONTROL sonde 301
FROZEN2 sonde 301
airep 303
airep 303
Continuous assimilation cycle started
6 hours before start date

b)

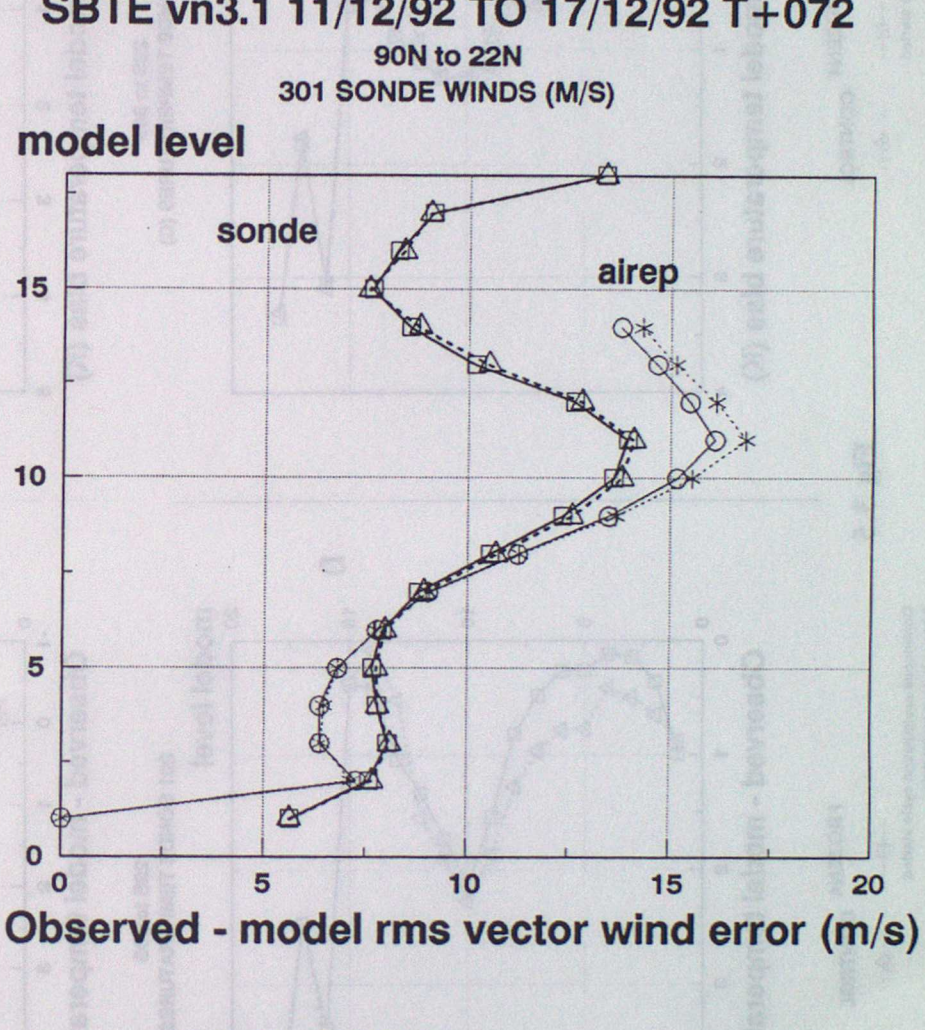
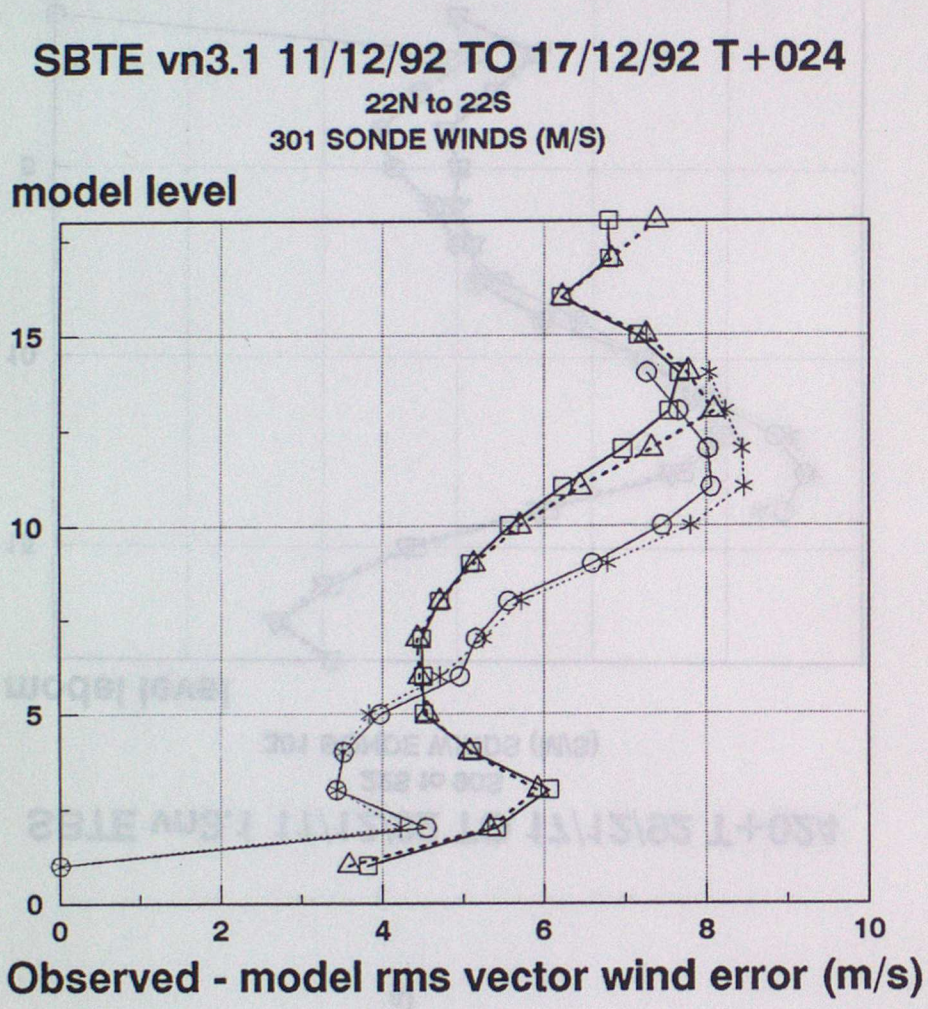

SBTE vn3.1 11/12/92 TO 17/12/92 T+072
90N to 22N
301 SONDE WINDS (M/S)
model level
sonde
airep
0
5
10
15
0
5
10
15
20
Observed - model rms vector wind error (m/s)
CONTROL sonde 301
FROZEN2 sonde 301
airep 303
airep 303
Continuous assimilation cycle started
6 hours before start date

Fig 3.6

a)


SBTE vn3.1 11/12/92 TO 17/12/92 T+024
22N to 22S
301 SONDE WINDS (M/S)
model level
0
5
10
15
0
2
4
6
8
10
Observed - model rms vector wind error (m/s)
CONTROL sonde 301
FROZEN2 sonde 301
airep 303
airep 303
Continuous assimilation cycle started
6 hours before start date

b)

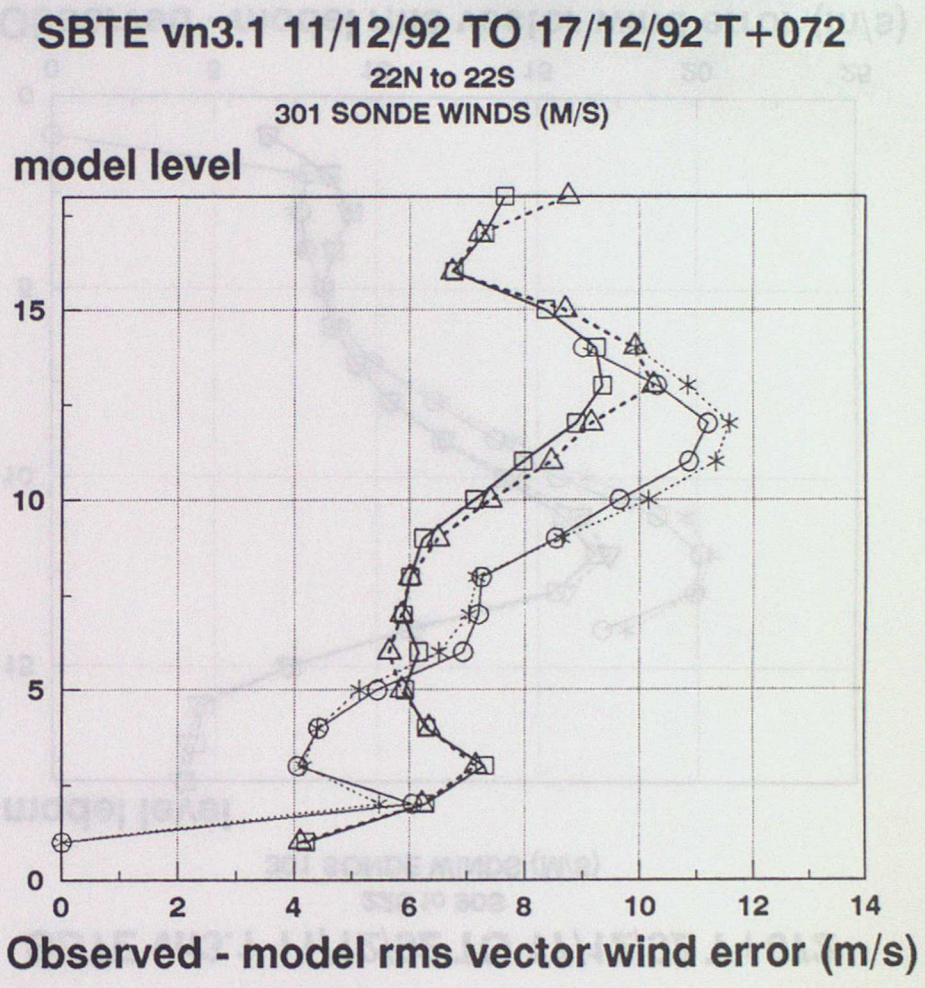
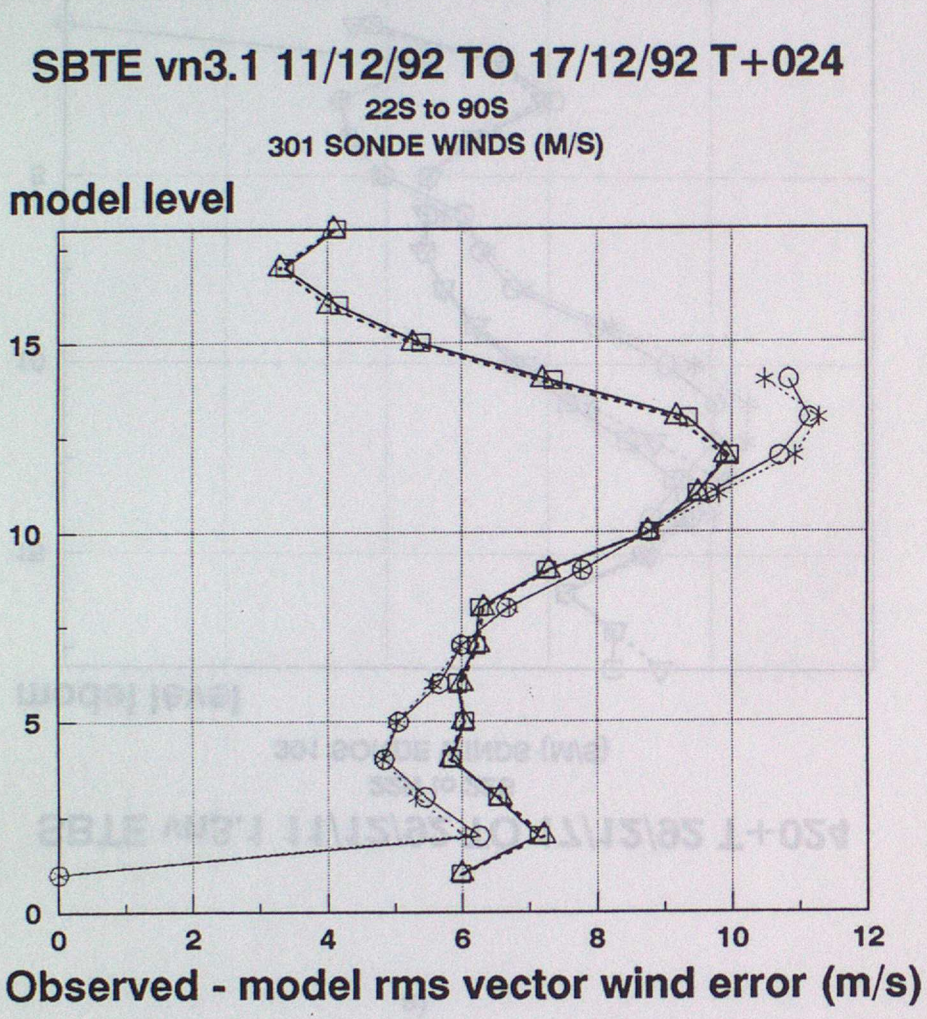

SBTE vn3.1 11/12/92 TO 17/12/92 T+072
22N to 22S
301 SONDE WINDS (M/S)
model level
0
5
10
15
0
2
4
6
8
10
12
14
Observed - model rms vector wind error (m/s)
CONTROL sonde 301
FROZEN2 sonde 301
airep 303
airep 303
Continuous assimilation cycle started
6 hours before start date

Fig 3.7

a)


SBTE vn3.1 11/12/92 TO 17/12/92 T+024
22S to 90S
301 SONDE WINDS (M/S)
model level
0
5
10
15
0
2
4
6
8
10
12
Observed - model rms vector wind error (m/s)
CONTROL sonde 301
FROZEN2 sonde 301
airep 303
airep 303
Continuous assimilation cycle started
6 hours before start date

b)

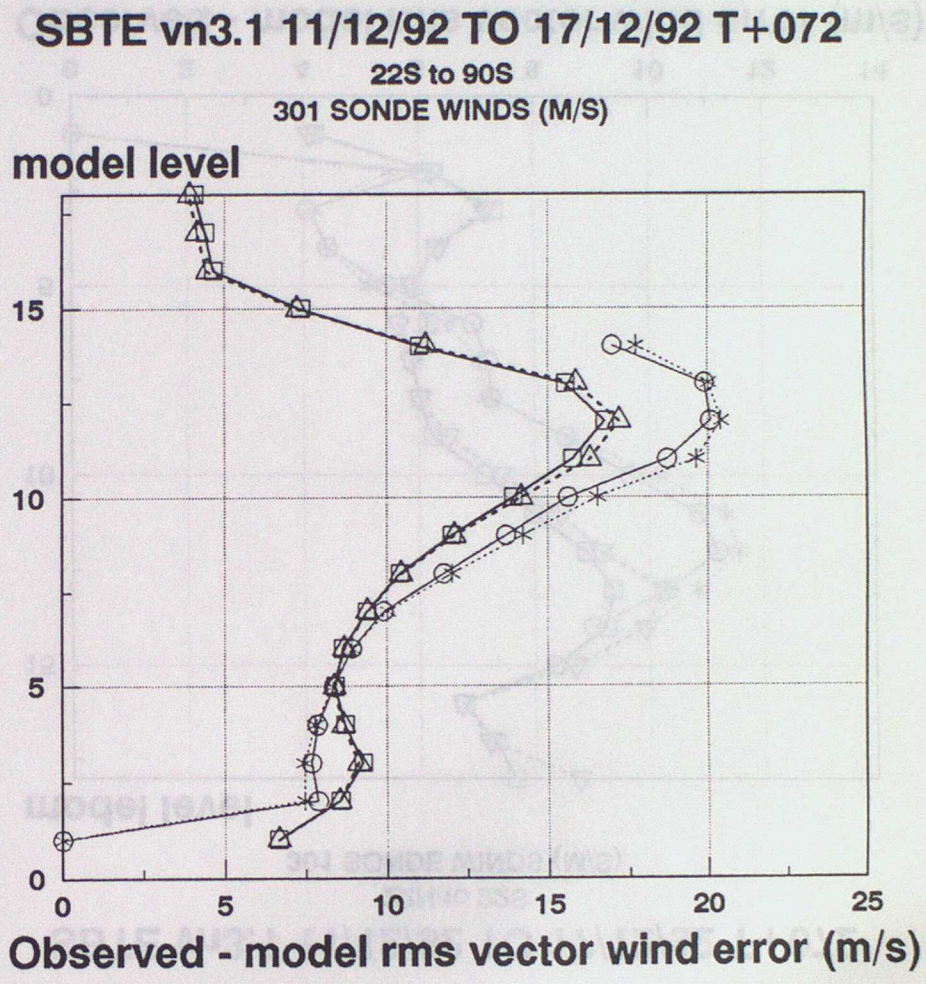
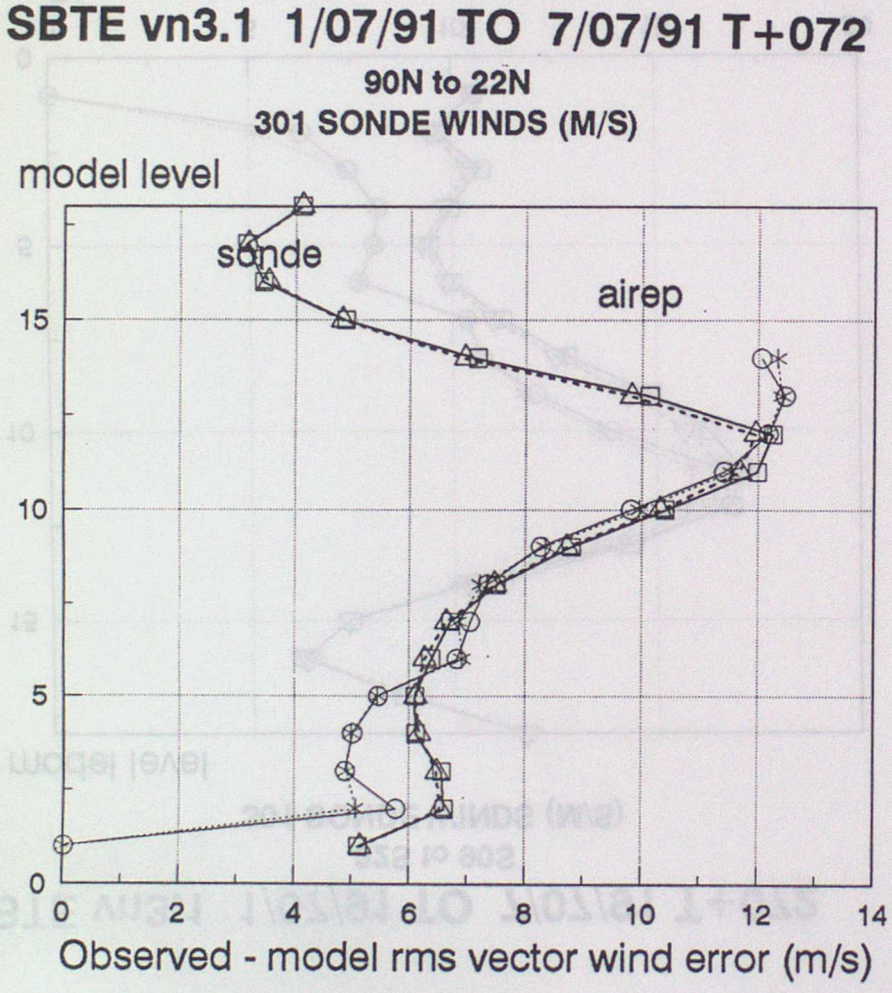

SBTE vn3.1 11/12/92 TO 17/12/92 T+072
22S to 90S
301 SONDE WINDS (M/S)
model level
0
5
10
15
0
5
10
15
20
25
Observed - model rms vector wind error (m/s)
CONTROL sonde 301
FROZEN2 sonde 301
airep 303
airep 303
Continuous assimilation cycle started
6 hours before start date

Fig 3.8

a)


SBTE vn3.1 1/07/91 TO 7/07/91 T+072
90N to 22N
301 SONDE WINDS (M/S)
model level
sonde
airep
0
5
10
15
0
2
4
6
8
10
12
14
Observed - model rms vector wind error (m/s)
FROZEN4 sonde 301
CONTROL2 sonde 301
airep 303
airep 303
Continuous assimilation cycle started
6 hours before start date

b)

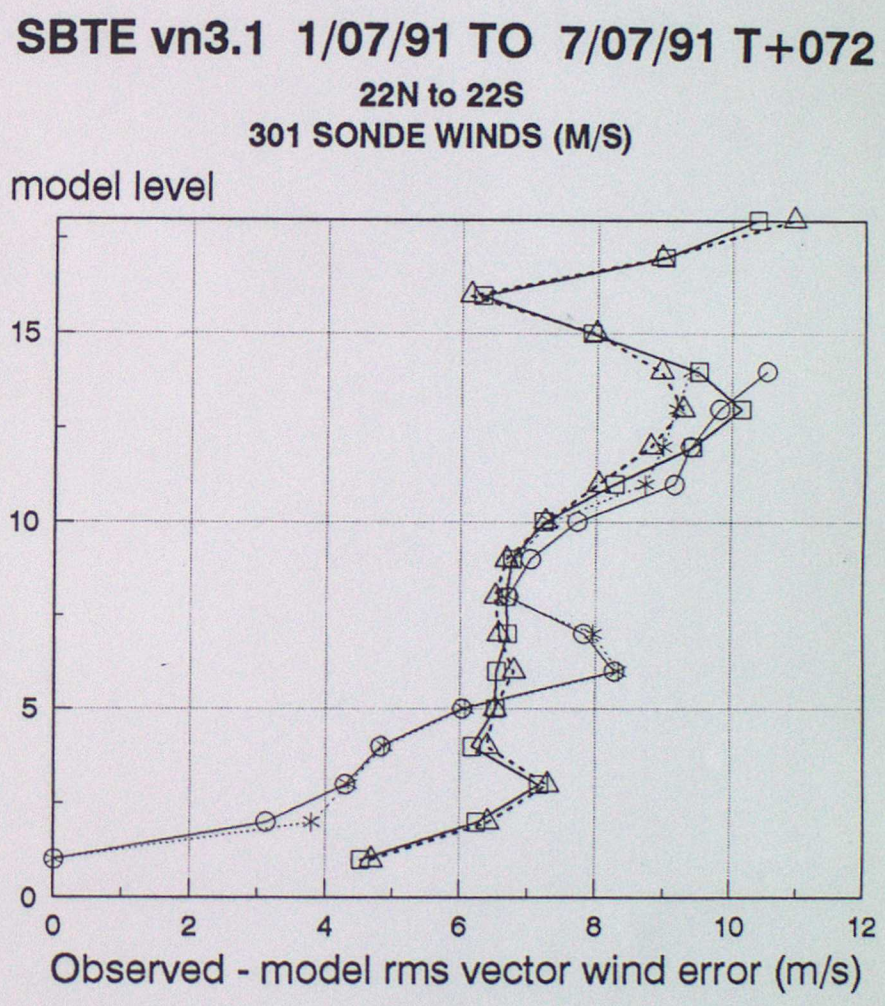
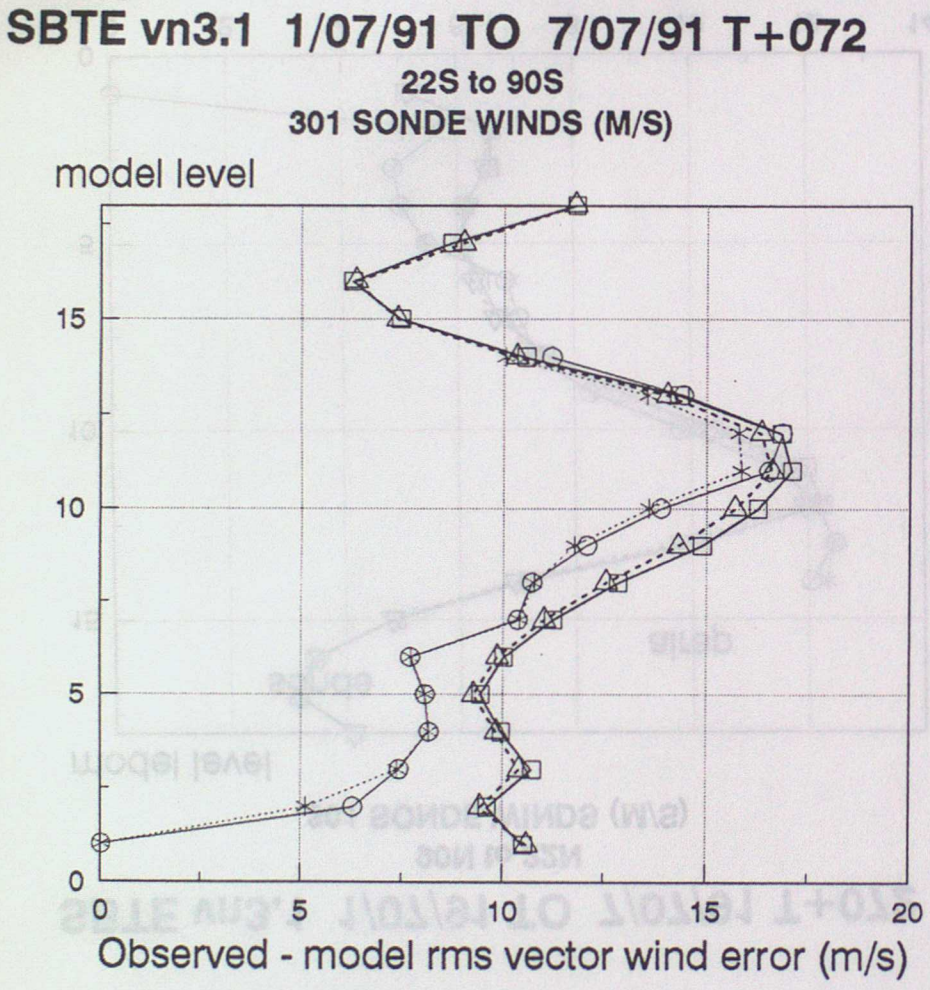
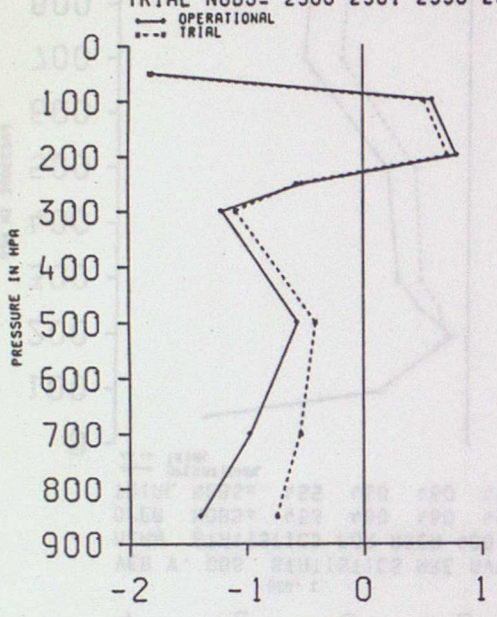

SBTE vn3.1 1/07/91 TO 7/07/91 T+072
22N to 22S
301 SONDE WINDS (M/S)
model level
0
5
10
15
0
2
4
6
8
10
12
Observed - model rms vector wind error (m/s)
FROZEN4 sonde 301
CONTROL2 sonde 301
airep 303
airep 303
Continuous assimilation cycle started
6 hours before start date

Fig 3.9

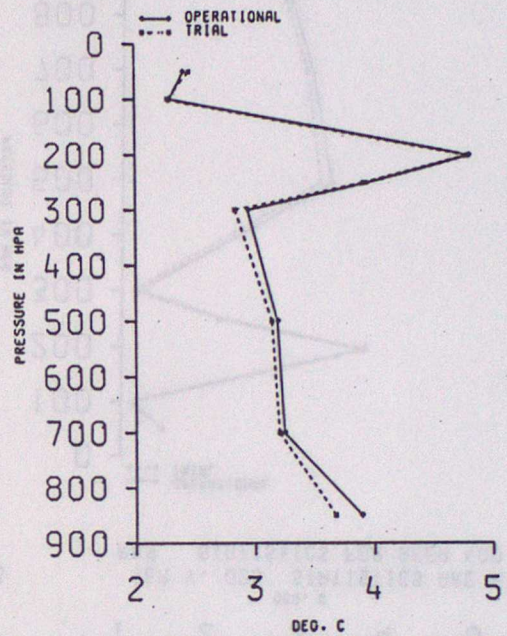
Fig 3.10


SBTE vn3.1 1/07/91 TO 7/07/91 T+072
22S to 90S
301 SONDE WINDS (M/S)
model level
0
5
10
15
0
5
10
15
20
Observed - model rms vector wind error (m/s)
FROZEN4 sonde 301
CONTROL2 sonde 301
airep 303
airep 303
Continuous assimilation cycle started
6 hours before start date

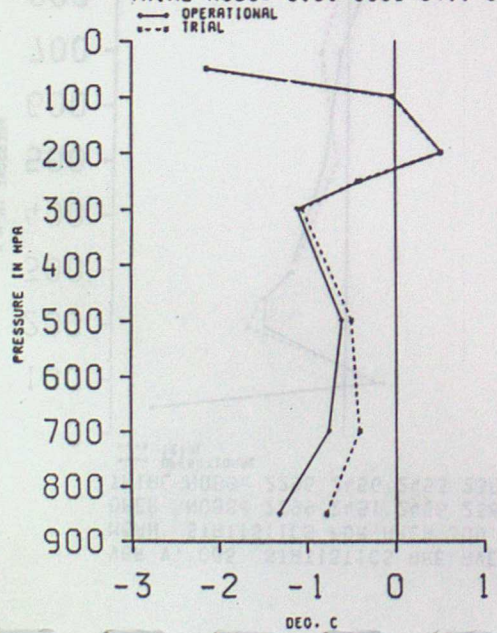
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 2 TEMPERATURET+120
OPER NOBS= 2365 2361 2357 2338 2334 2329 2290 1839
TRIAL NOBS= 2366 2361 2358 2338 2334 2329 2290 1839



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 2 TEMPERATURET+120



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 200 TEMPERATURET+120
OPER NOBS= 6137 6368 6410 6300 6257 6236 6006 4918
TRIAL NOBS= 6139 6368 6411 6299 6256 6236 6006 4918



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 200 TEMPERATURET+120

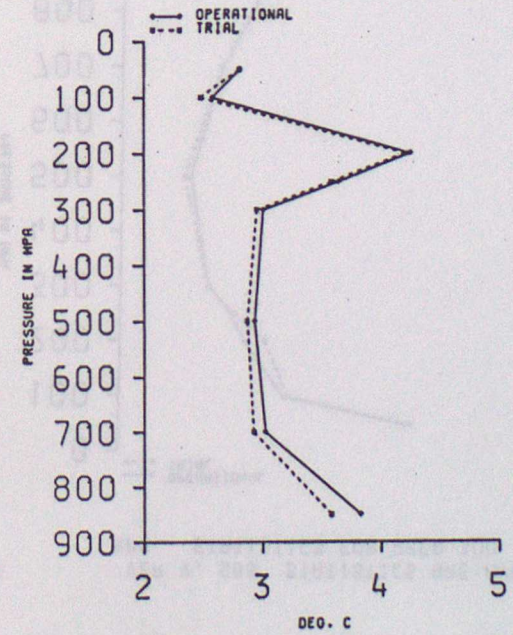
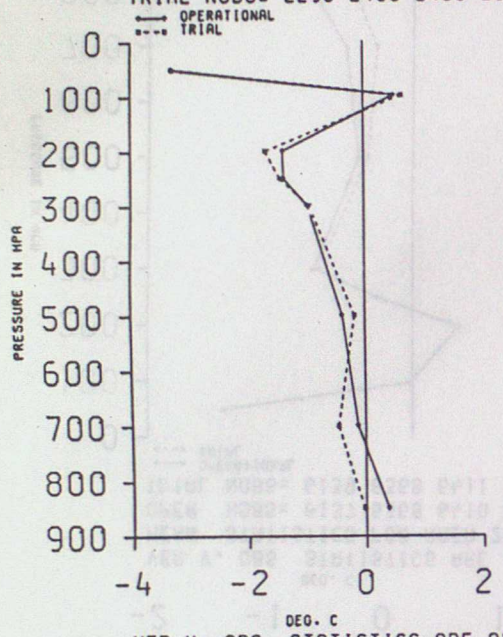
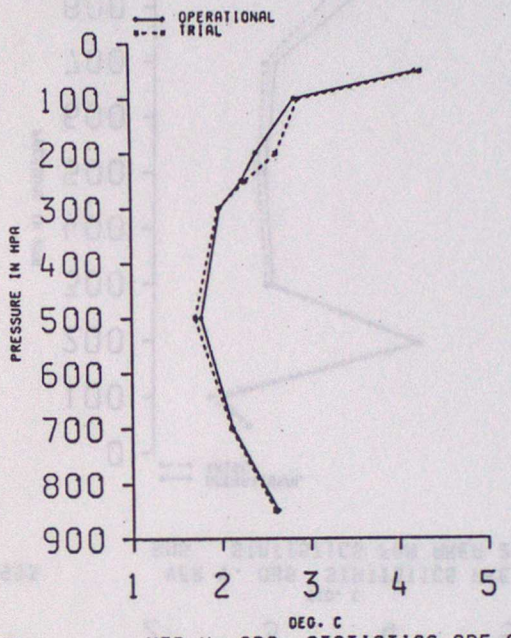


Fig 4.01

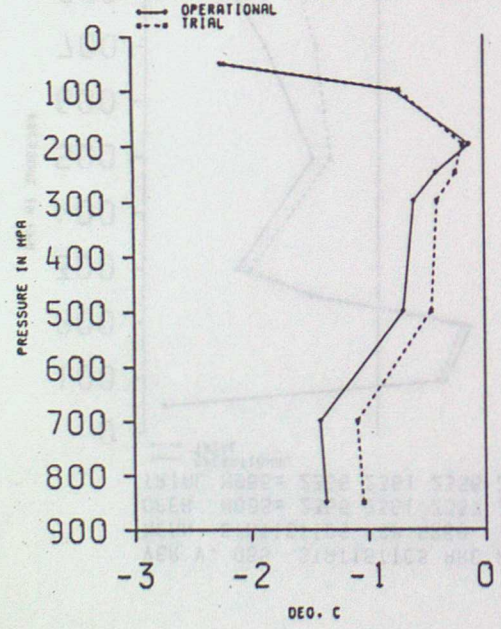
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 300 TEMPERATURET+120
OPER NOBS= 2299 2451 2456 2387 2347 2376 2245 1513
TRIAL NOBS= 2296 2456 2453 2385 2346 2376 2246 1515



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 300 TEMPERATURET+120



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 400 TEMPERATURET+120
OPER NOBS= 453 460 460 455 451 448 432 338
TRIAL NOBS= 455 460 460 455 451 448 432 338



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 400 TEMPERATURET+120

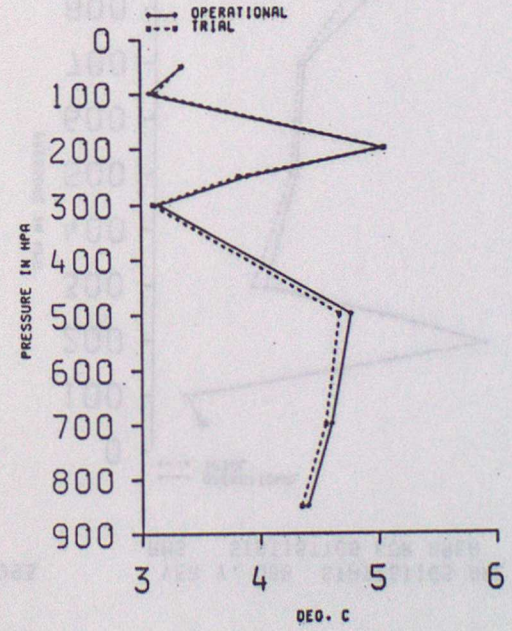
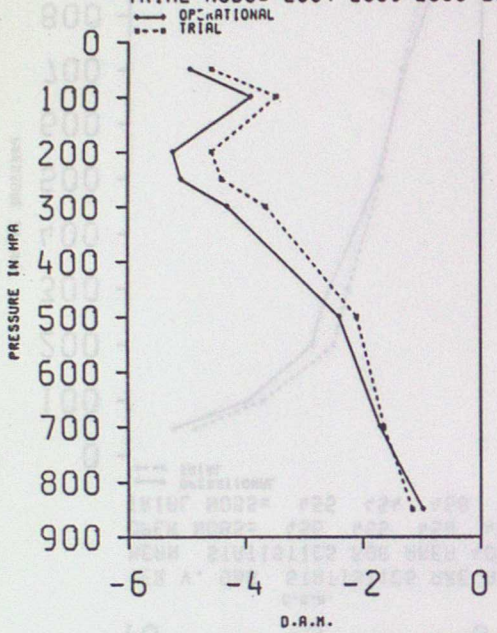
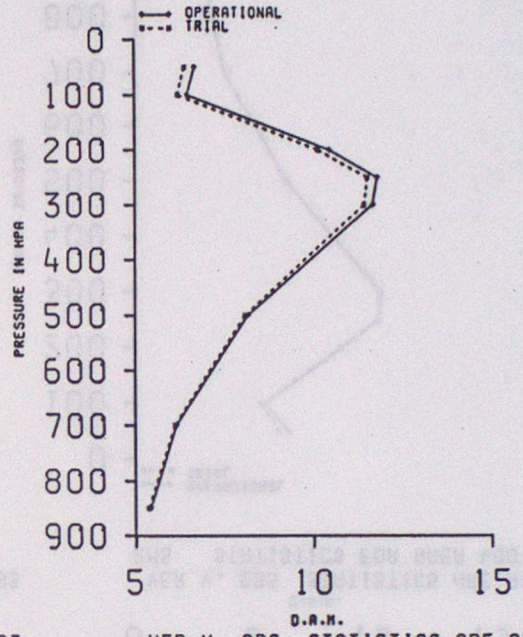


Fig 4.02

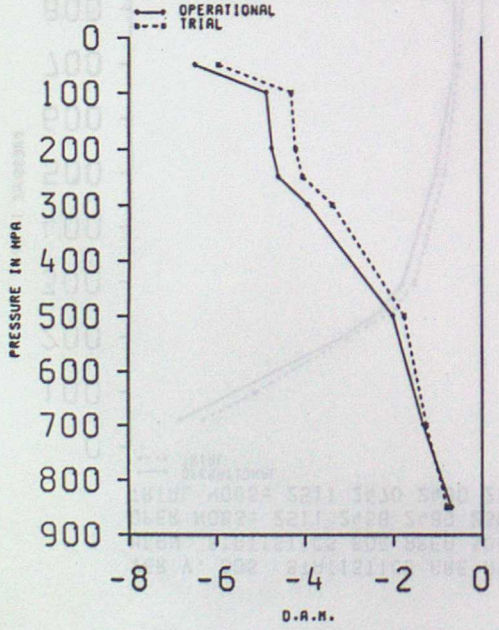
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 2 HEIGHT T+120
OPER NOBS= 2364 2359 2363 2338 2334 2329 2292 1851
TRIAL NOBS= 2364 2359 2363 2338 2334 2329 2292 1851



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 2 HEIGHT T+120



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 200 HEIGHT T+120
OPER NOBS= 6373 6359 6424 6305 6257 6233 5974 4891
TRIAL NOBS= 6372 6358 6424 6305 6257 6232 5974 4890



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 200 HEIGHT T+120

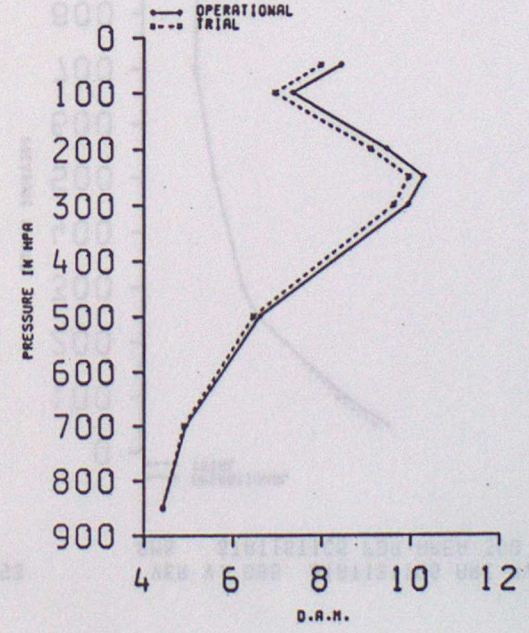
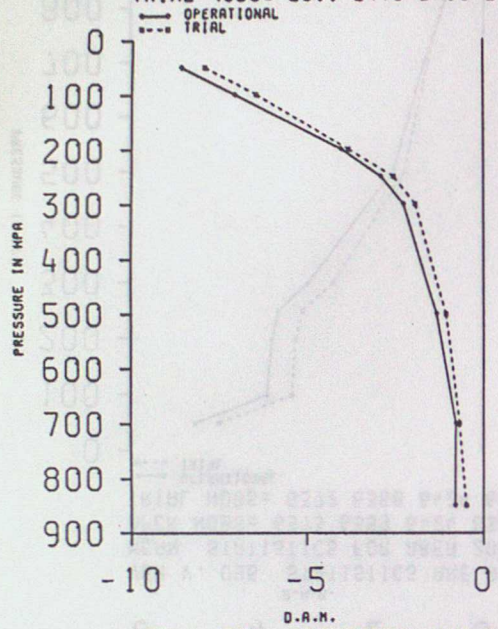
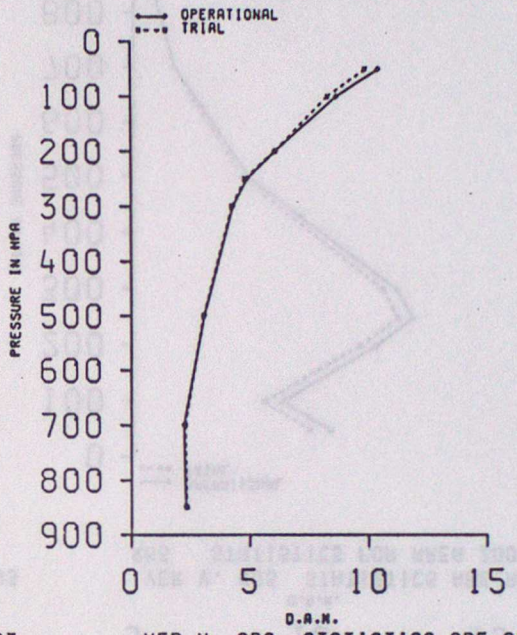


Fig 4.03

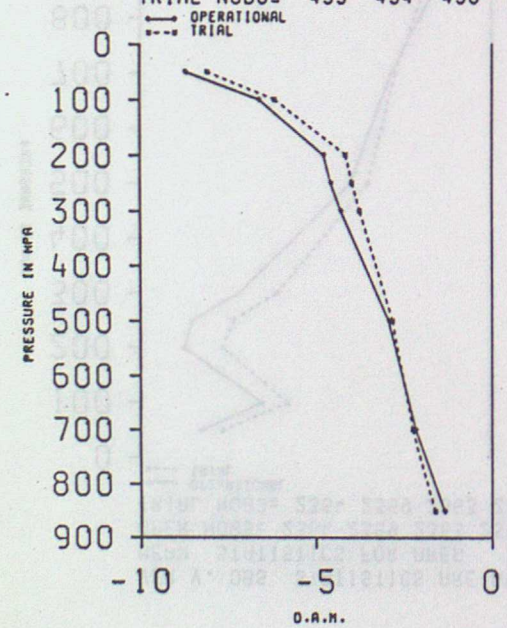
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 300 HEIGHT T+120
OPER NOBS= 2511 2468 2480 2381 2330 2338 2165 1487
TRIAL NOBS= 2511 2470 2480 2379 2326 2340 2170 1487



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 300 HEIGHT T+120



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 400 HEIGHT T+120
OPER NOBS= 456 455 458 454 453 447 433 353
TRIAL NOBS= 455 454 458 454 453 447 433 353



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 400 HEIGHT T+120

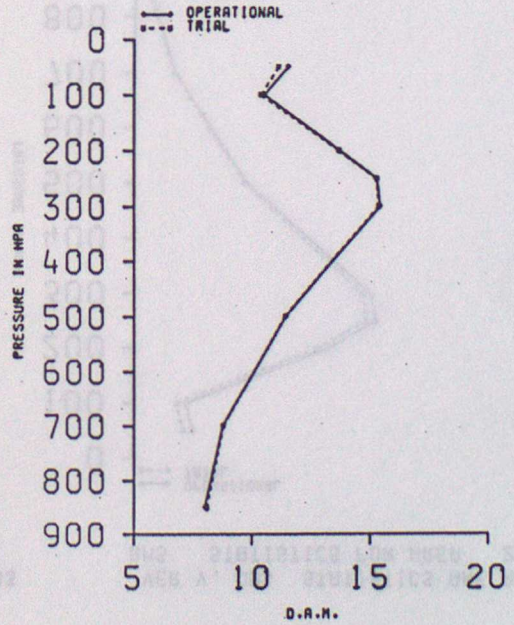
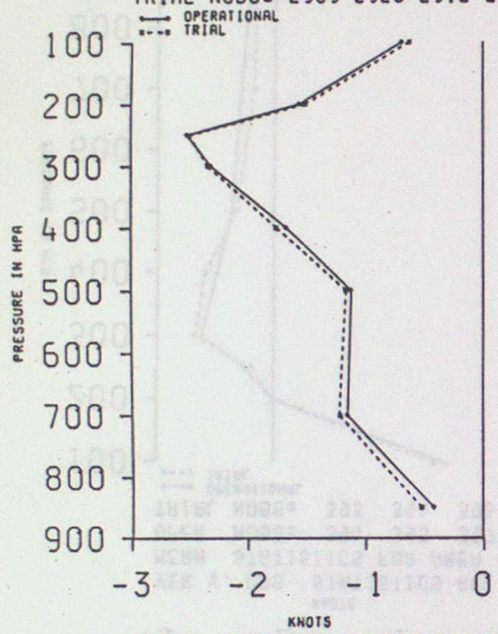
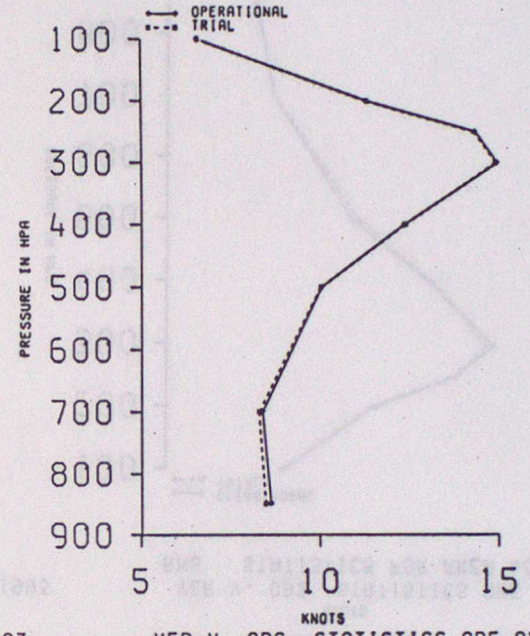


Fig 4.04

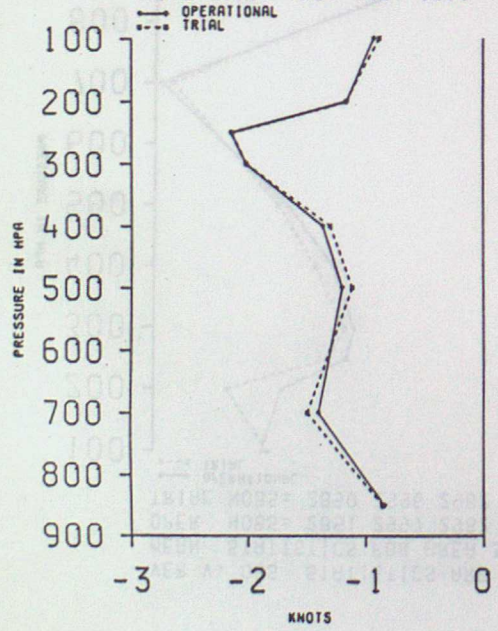
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 2 WIND T+24
OPER NOBS= 2909 2923 2911 2902 2871 2841 2832 2779
TRIAL NOBS= 2909 2923 2912 2902 2870 2841 2832 2779



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 2 WIND T+24



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 200 WIND T+24
OPER NOBS= 7625 7956 8002 7948 7828 7754 7677 7322
TRIAL NOBS= 7624 7957 8003 7949 7828 7754 7677 7322



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 200 WIND T+24

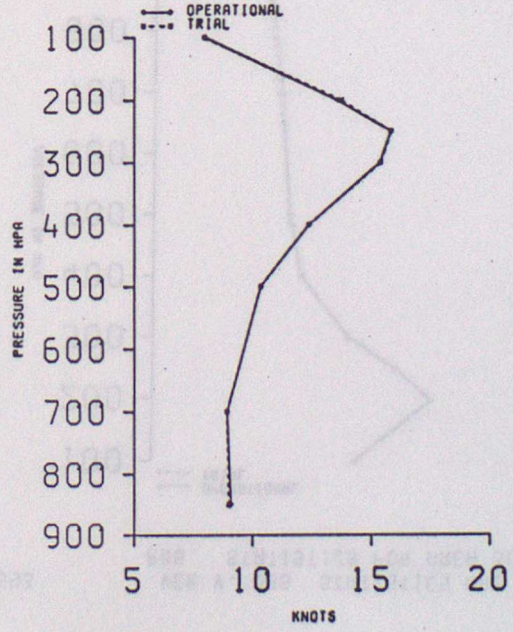
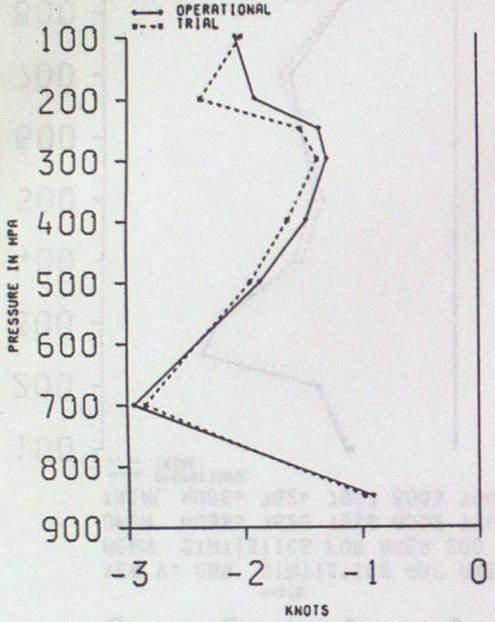
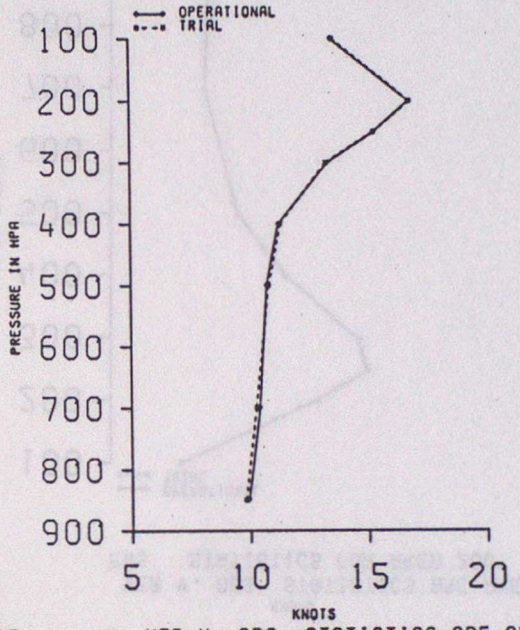


Fig 4.05

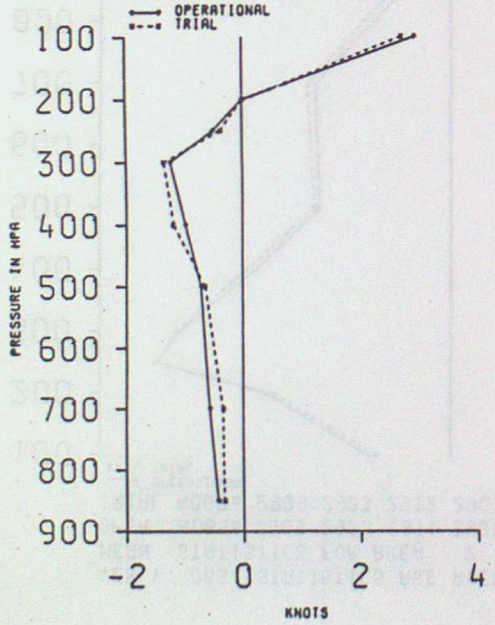
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 300 WIND T+24
OPER NOBS= 2851 2997 2982 2930 2890 2831 2773 2577
TRIAL NOBS= 2850 2996 2982 2930 2890 2832 2771 2577



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 300 WIND T+24



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 400 WIND T+24
OPER NOBS= 394 393 397 389 381 379 374 374
TRIAL NOBS= 393 394 396 390 380 379 375 374



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 400 WIND T+24

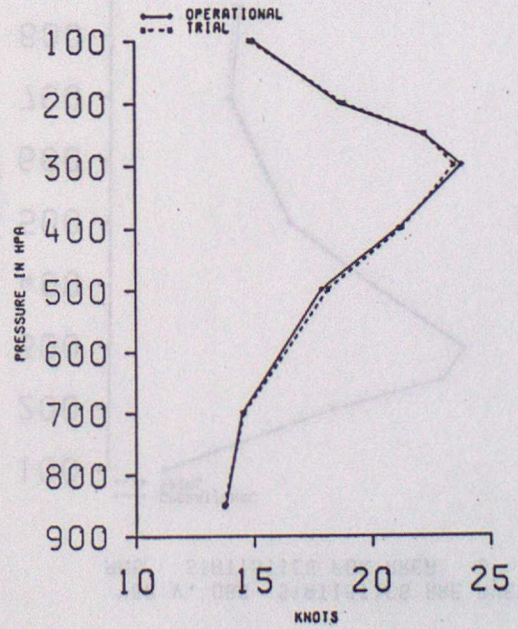
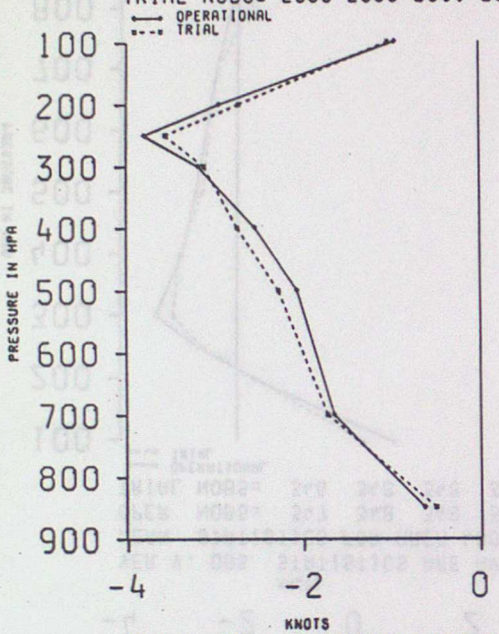
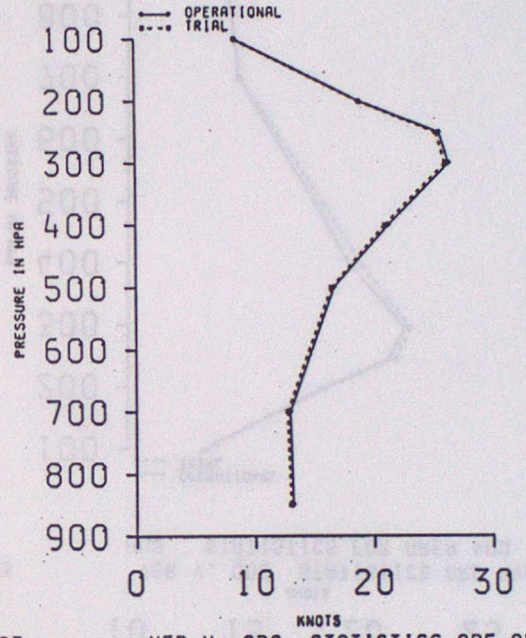


Fig 4.06

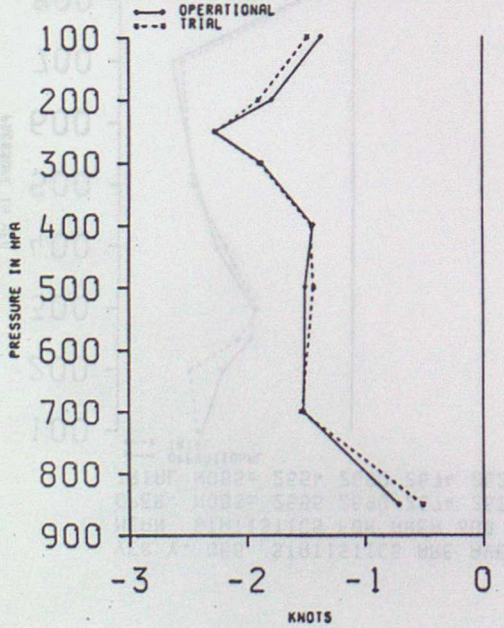
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 2 WIND T+72
OPER NOBS= 2585 2600 2590 2587 2568 2543 2530 2478
TRIAL NOBS= 2585 2600 2591 2587 2567 2543 2530 2478



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 2 WIND T+72



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 200 WIND T+72
OPER NOBS= 6794 7094 7137 7089 7001 6928 6852 6534
TRIAL NOBS= 6793 7095 7138 7090 6999 6930 6852 6534



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 200 WIND T+72

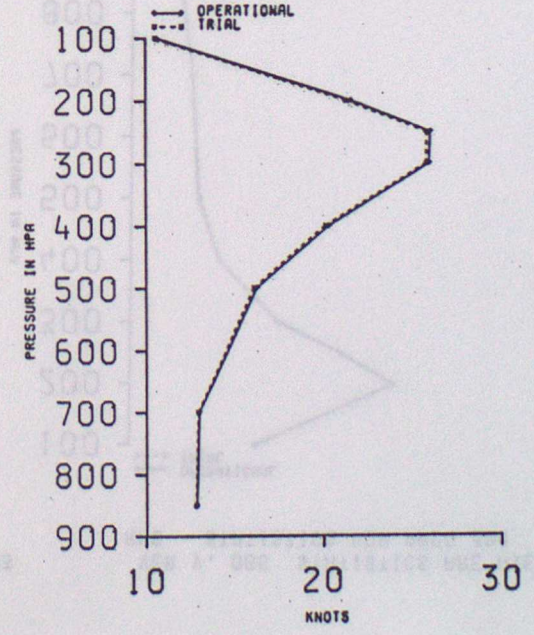
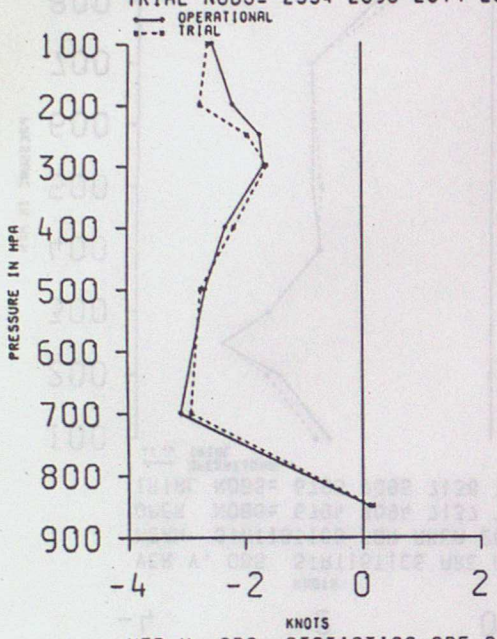
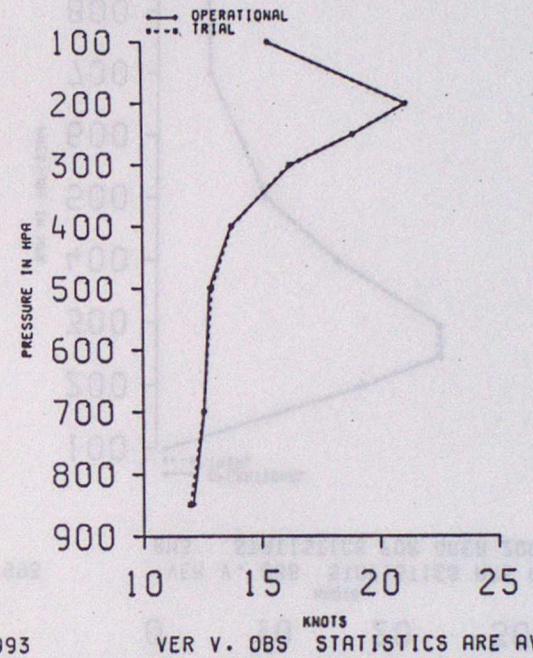


Fig 4.07

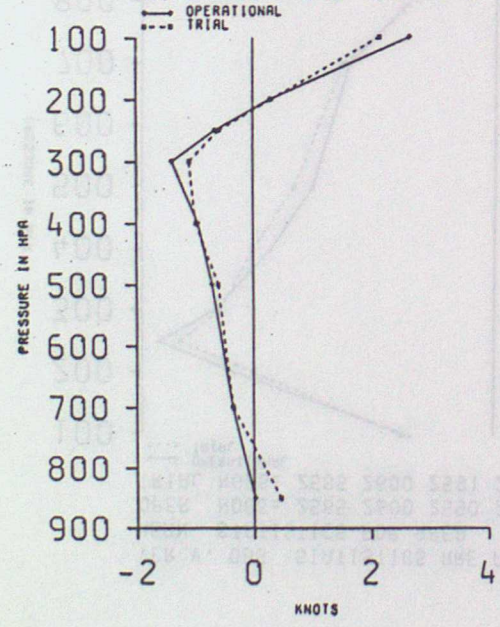
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 300 WIND T+72
OPER NOBS= 2555 2690 2674 2627 2590 2537 2483 2307
TRIAL NOBS= 2554 2690 2674 2627 2591 2538 2483 2307



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 300 WIND T+72



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 400 WIND T+72
OPER NOBS= 347 348 349 343 337 334 328 329
TRIAL NOBS= 346 348 348 344 336 334 329 329



VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 400 WIND T+72

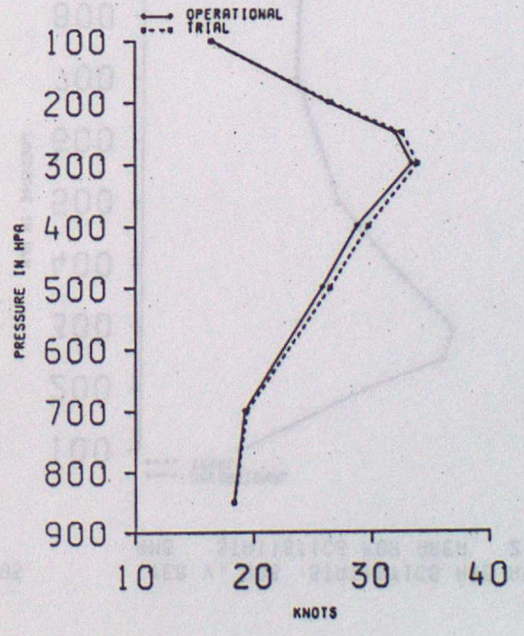
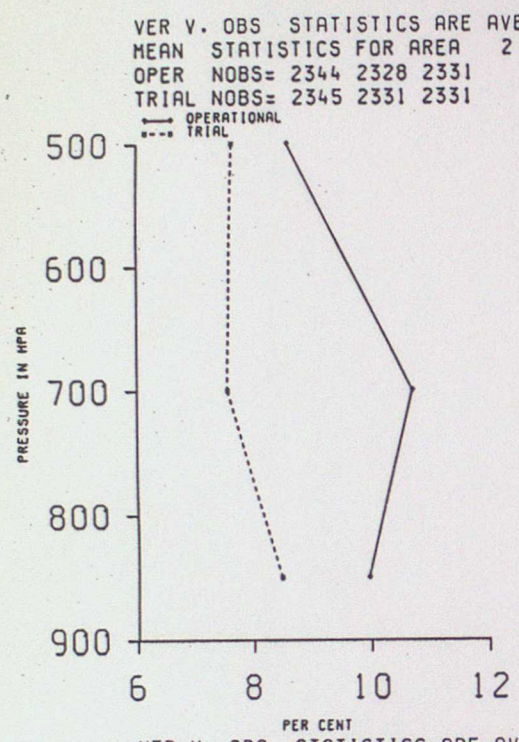
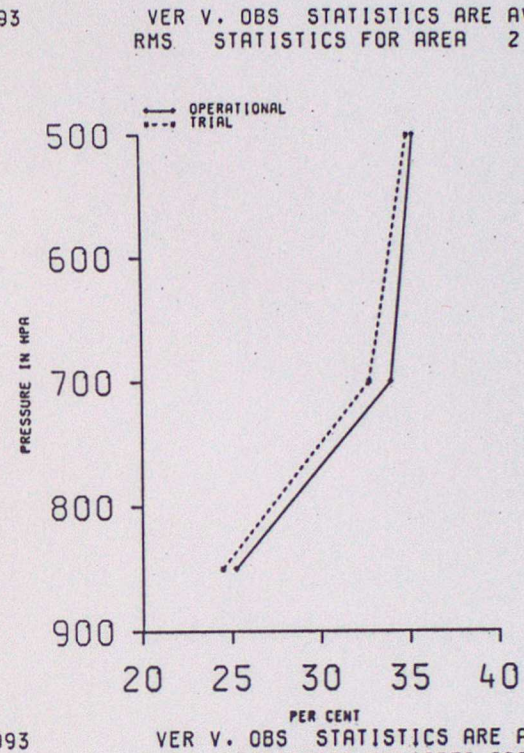
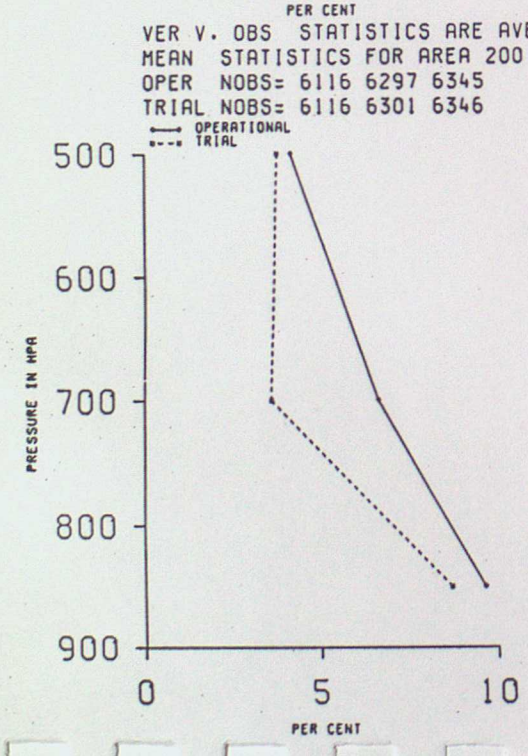


Fig 4.08


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 2 REL HUM T+120
OPER NOBS= 2344 2328 2331
TRIAL NOBS= 2345 2331 2331
OPERATIONAL
TRIAL
500
600
700
800
900
PRESSURE IN HPA
6
8
10
12
PER CENT


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 2 REL HUM T+120
OPERATIONAL
TRIAL
500
600
700
800
900
PRESSURE IN HPA
20
25
30
35
40
PER CENT


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 200 REL HUM T+120
OPER NOBS= 6116 6297 6345
TRIAL NOBS= 6116 6301 6346
OPERATIONAL
TRIAL
500
600
700
800
900
PRESSURE IN HPA
0
5
10
PER CENT

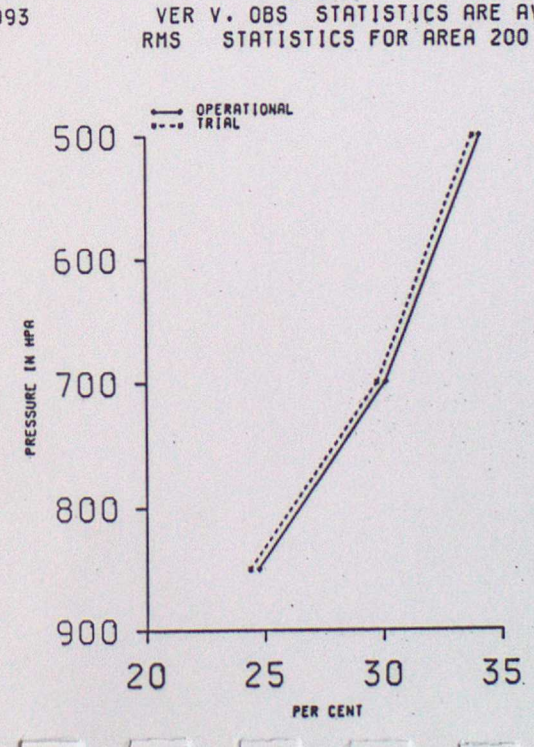
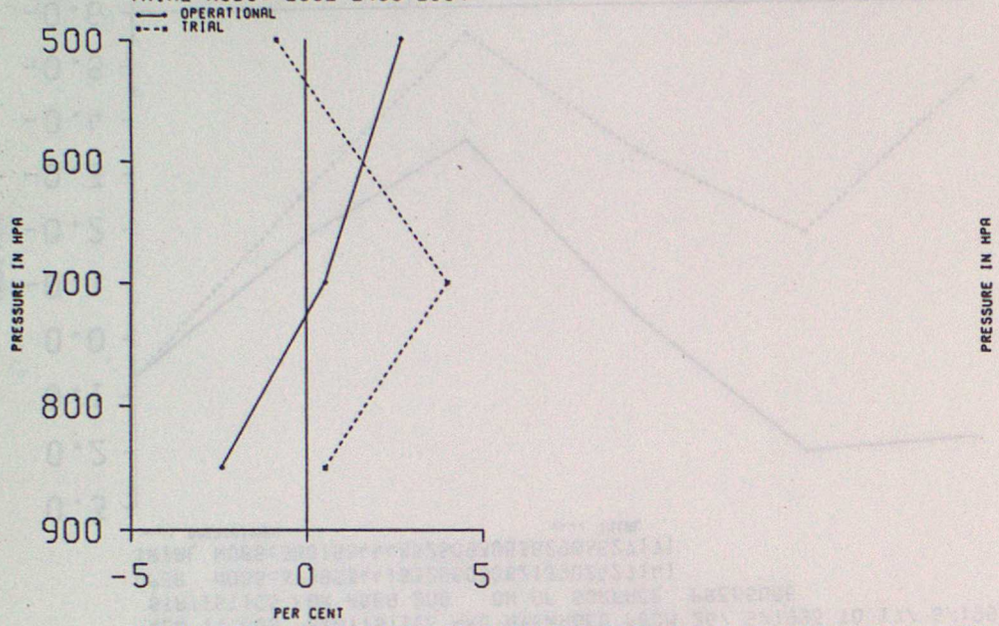
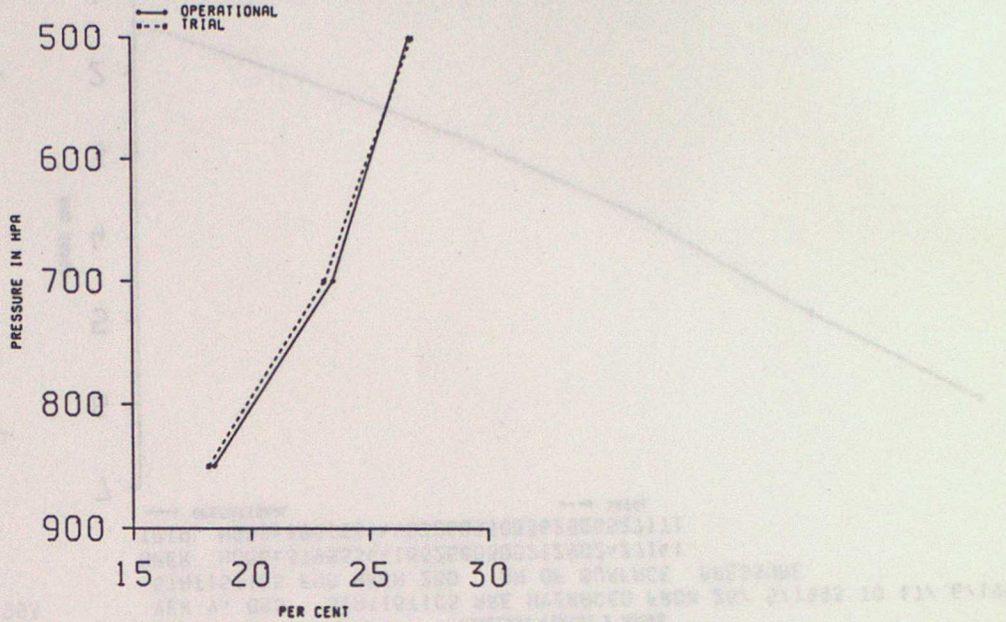
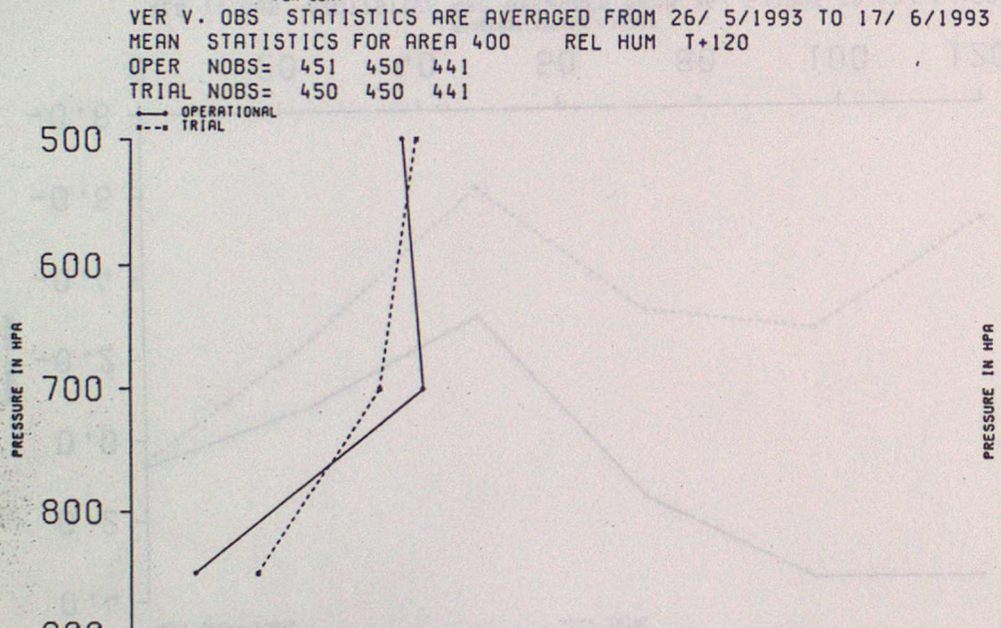

VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 200 REL HUM T+120
OPERATIONAL
TRIAL
500
600
700
800
900
PRESSURE IN HPA
20
25
30
35
PER CENT

Fig 4.09


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 300 REL HUM T+120
OPER NOBS= 2301 2449 2377
TRIAL NOBS= 2302 2450 2384
OPERATIONAL
TRIAL
500
600
700
800
900
PRESSURE IN HPA
-5
0
5
PER CENT


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 300 REL HUM T+120
OPERATIONAL
TRIAL
500
600
700
800
900
PRESSURE IN HPA
15
20
25
30
PER CENT


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
MEAN STATISTICS FOR AREA 400 REL HUM T+120
OPER NOBS= 451 450 441
TRIAL NOBS= 450 450 441
OPERATIONAL
TRIAL
500
600
700
800
900
PRESSURE IN HPA
4
6
8
10
12
PER CENT

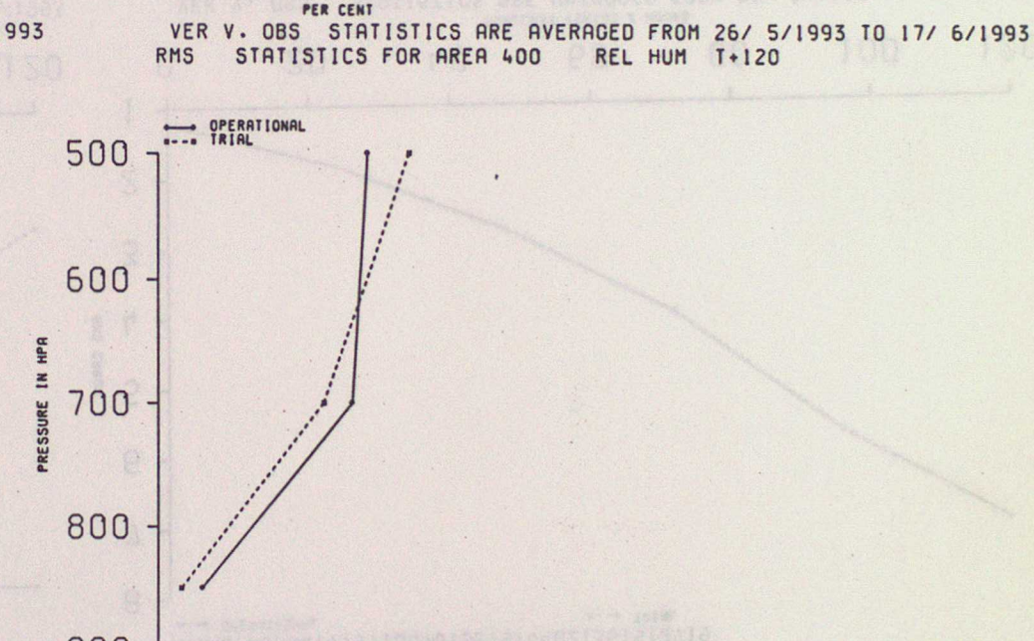
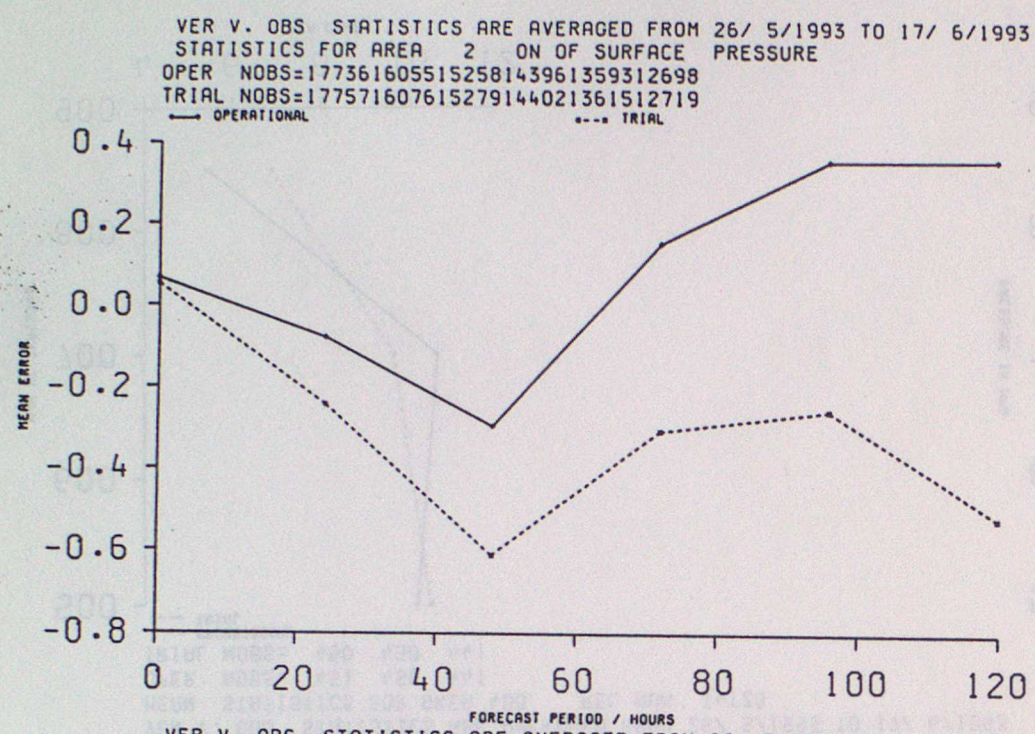
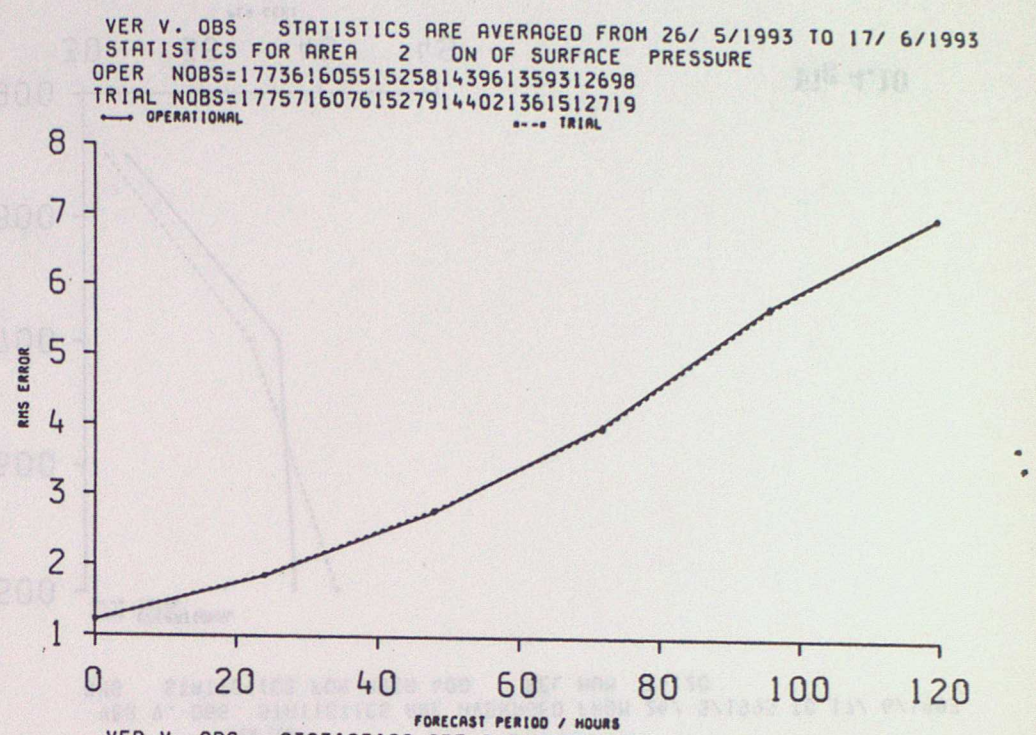
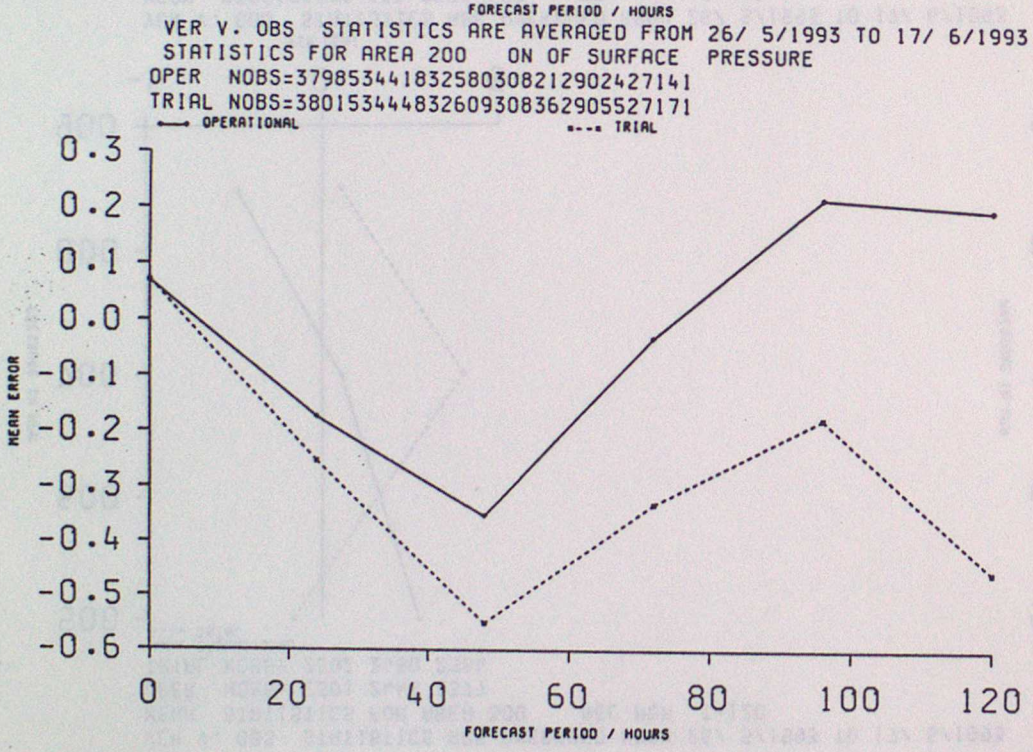

VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
RMS STATISTICS FOR AREA 400 REL HUM T+120
OPERATIONAL
TRIAL
500
600
700
800
900
PRESSURE IN HPA
30
35
40
45
PER CENT

Fig 4.10


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 2 ON OF SURFACE PRESSURE
OPER NOBS=17736160551525814396135931269 8
TRIAL NOBS=17757160761527914402136151271 9
OPERATIONAL
TRIAL
MEAN ERROR
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 2 ON OF SURFACE PRESSURE
OPER NOBS=17736160551525814396135931269 8
TRIAL NOBS=17757160761527914402136151271 9
OPERATIONAL
TRIAL
RMS ERROR
8
7
6
5
4
3
2
1
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 200 ON OF SURFACE PRESSURE
OPER NOBS=37985344183258030821290242714 1
TRIAL NOBS=38015344483260930836290552717 1
OPERATIONAL
TRIAL
MEAN ERROR
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS

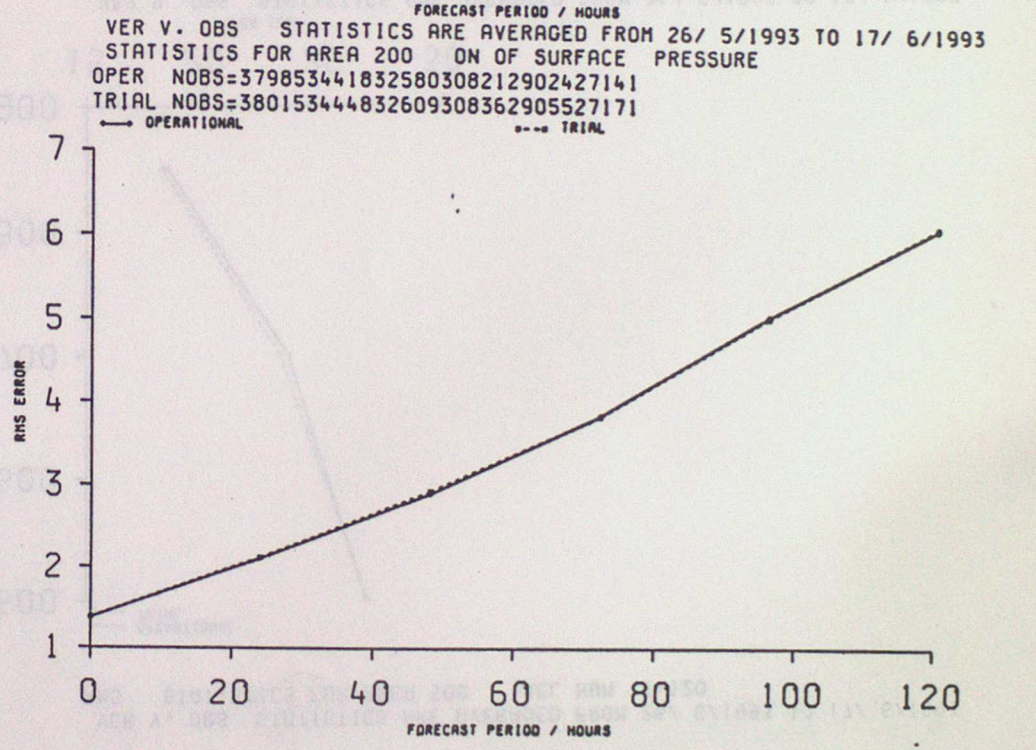
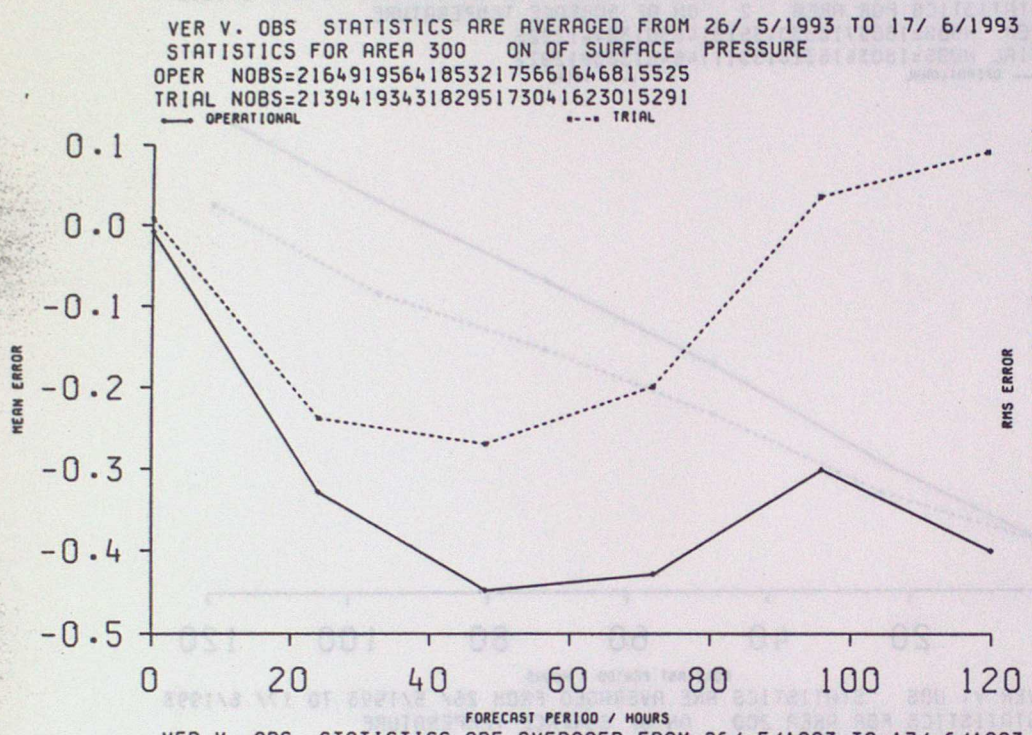
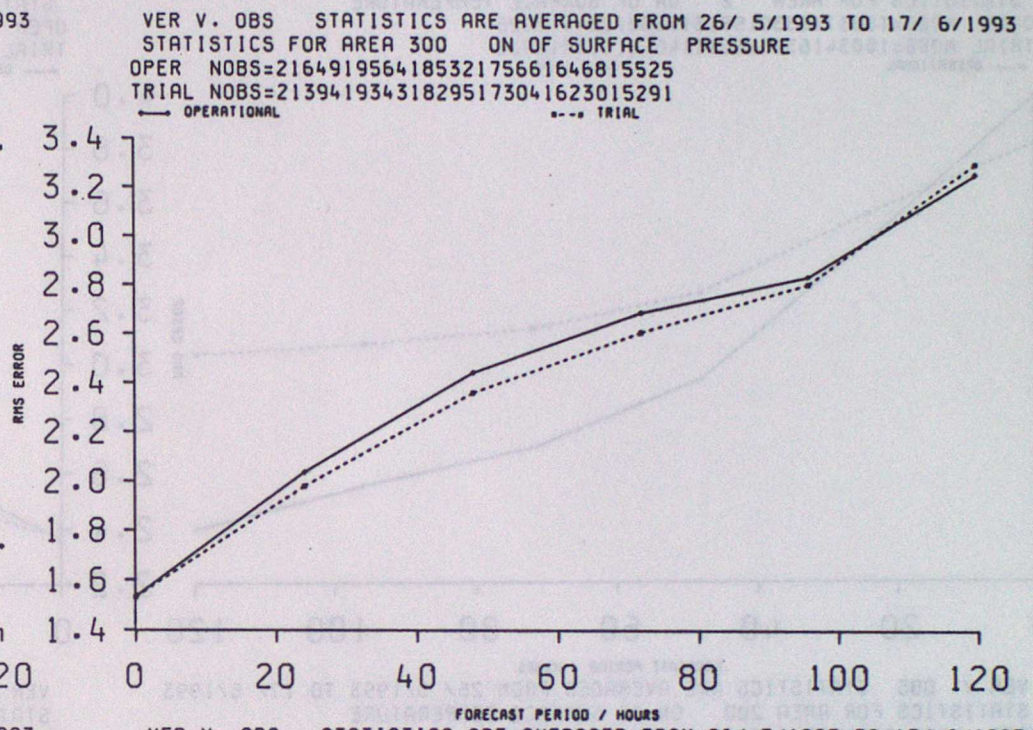
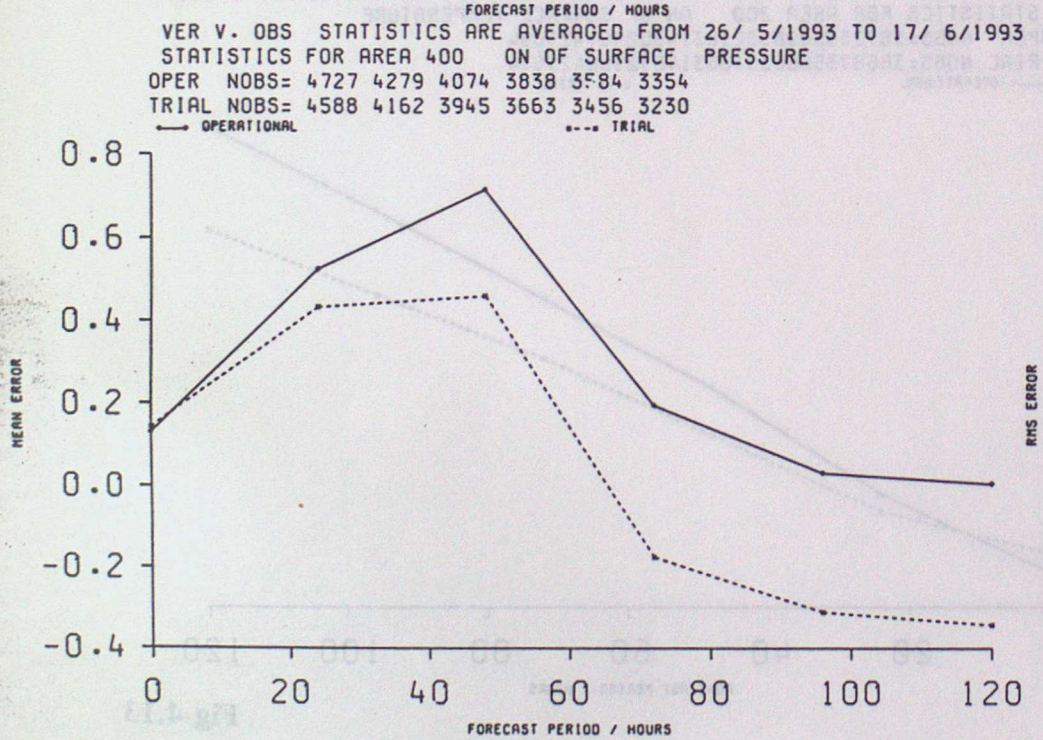

VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 200 ON OF SURFACE PRESSURE
OPER NOBS=37985344183258030821290242714 1
TRIAL NOBS=38015344483260930836290552717 1
OPERATIONAL
TRIAL
RMS ERROR
7
6
5
4
3
2
1
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS

Fig 4.11


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 300 ON OF SURFACE PRESSURE
OPER NOBS=2164919564185321756616468155 25
TRIAL NOBS=2139419343182951730416230152 91
OPERATIONAL
TRIAL
MEAN ERROR
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 300 ON OF SURFACE PRESSURE
OPER NOBS=2164919564185321756616468155 25
TRIAL NOBS=2139419343182951730416230152 91
OPERATIONAL
TRIAL
RMS ERROR
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 400 ON OF SURFACE PRESSURE
OPER NOBS= 4727 4279 4074 3838 3584 3354
TRIAL NOBS= 4588 4162 3945 3663 3456 3230
OPERATIONAL
TRIAL
MEAN ERROR
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS

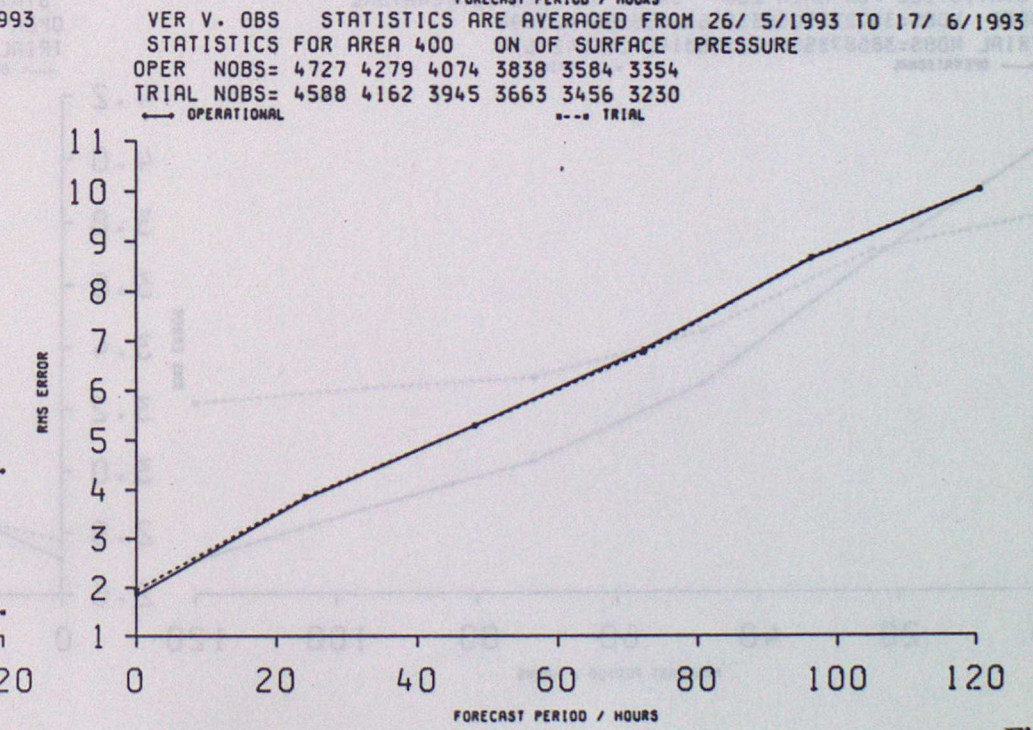
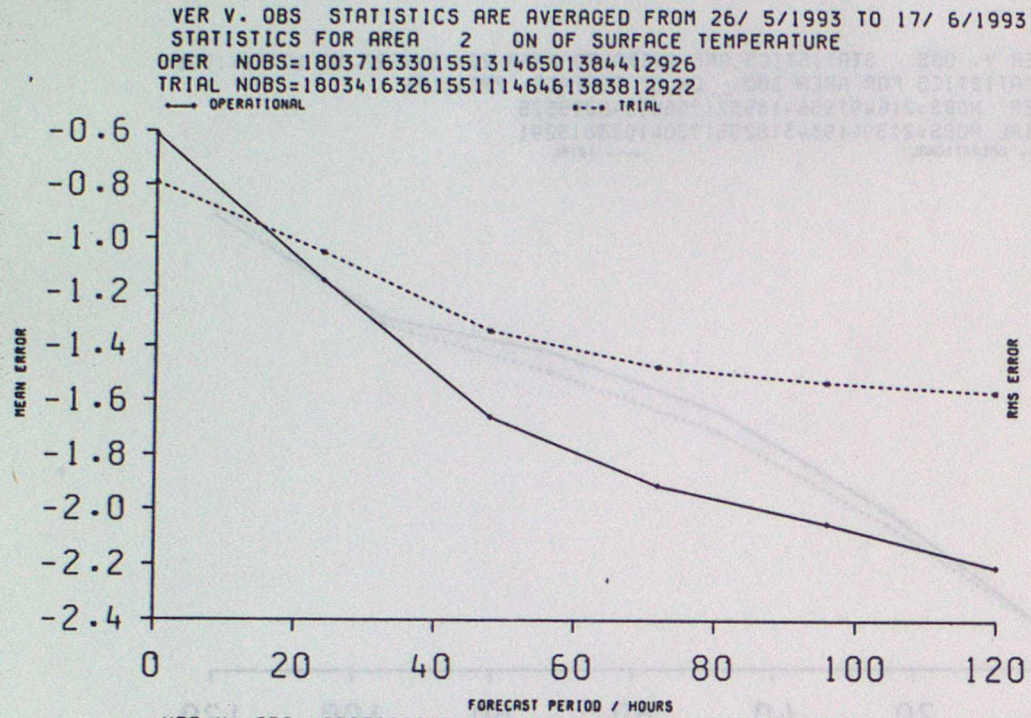
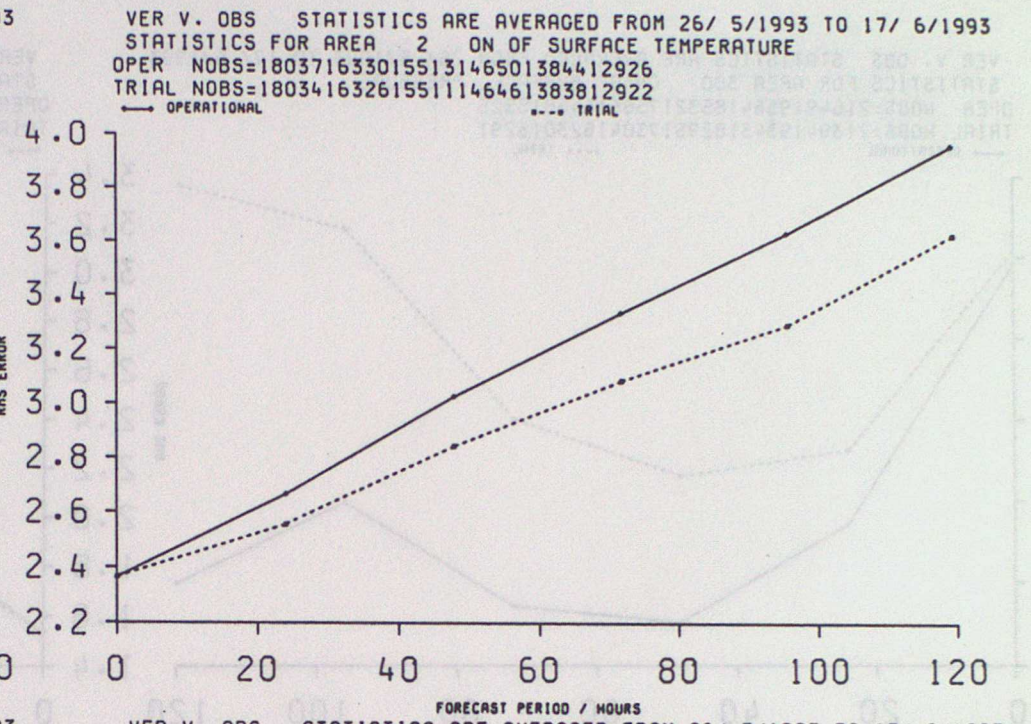
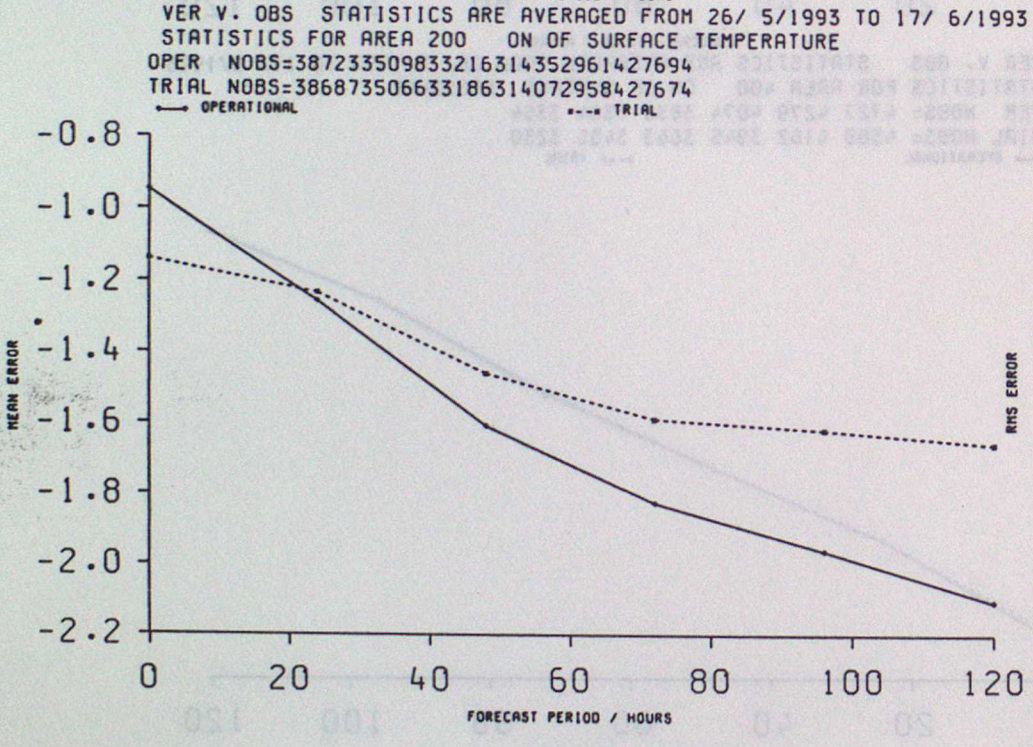

VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 400 ON OF SURFACE PRESSURE
OPER NOBS= 4727 4279 4074 3838 3584 3354
TRIAL NOBS= 4588 4162 3945 3663 3456 3230
OPERATIONAL
TRIAL
RMS ERROR
11
10
9
8
7
6
5
4
3
2
1
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS

Fig 4.12


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 2 ON OF SURFACE TEMPERATURE
OPER NOBS=1803716330155131465013844129 26
TRIAL NOBS=1803416326155111464613838129 22
OPERATIONAL
TRIAL
MEAN ERROR
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 2 ON OF SURFACE TEMPERATURE
OPER NOBS=1803716330155131465013844129 26
TRIAL NOBS=1803416326155111464613838129 22
OPERATIONAL
TRIAL
RMS ERROR
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS


VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 200 ON OF SURFACE TEMPERATURE
OPER NOBS=3872335098332163143529614276 94
TRIAL NOBS=3868735066331863140729584276 74
OPERATIONAL
TRIAL
MEAN ERROR
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS

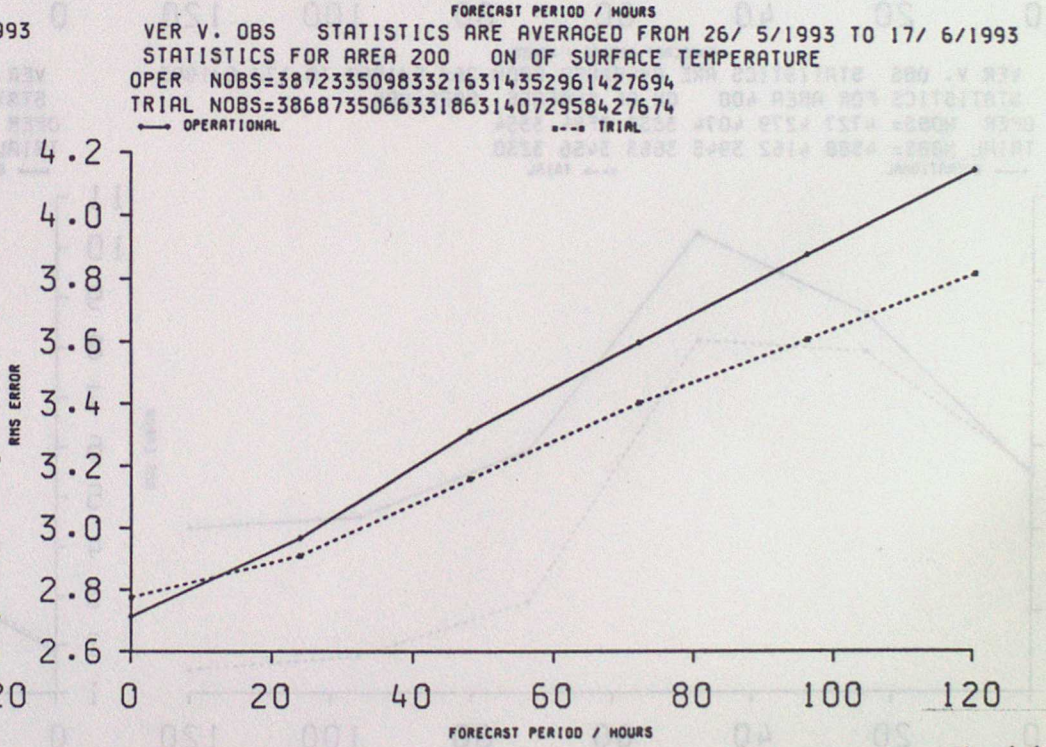

VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 200 ON OF SURFACE TEMPERATURE
OPER NOBS=3872335098332163143529614276 94
TRIAL NOBS=3868735066331863140729584276 74
OPERATIONAL
TRIAL
RMS ERROR
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS

Fig 4.13

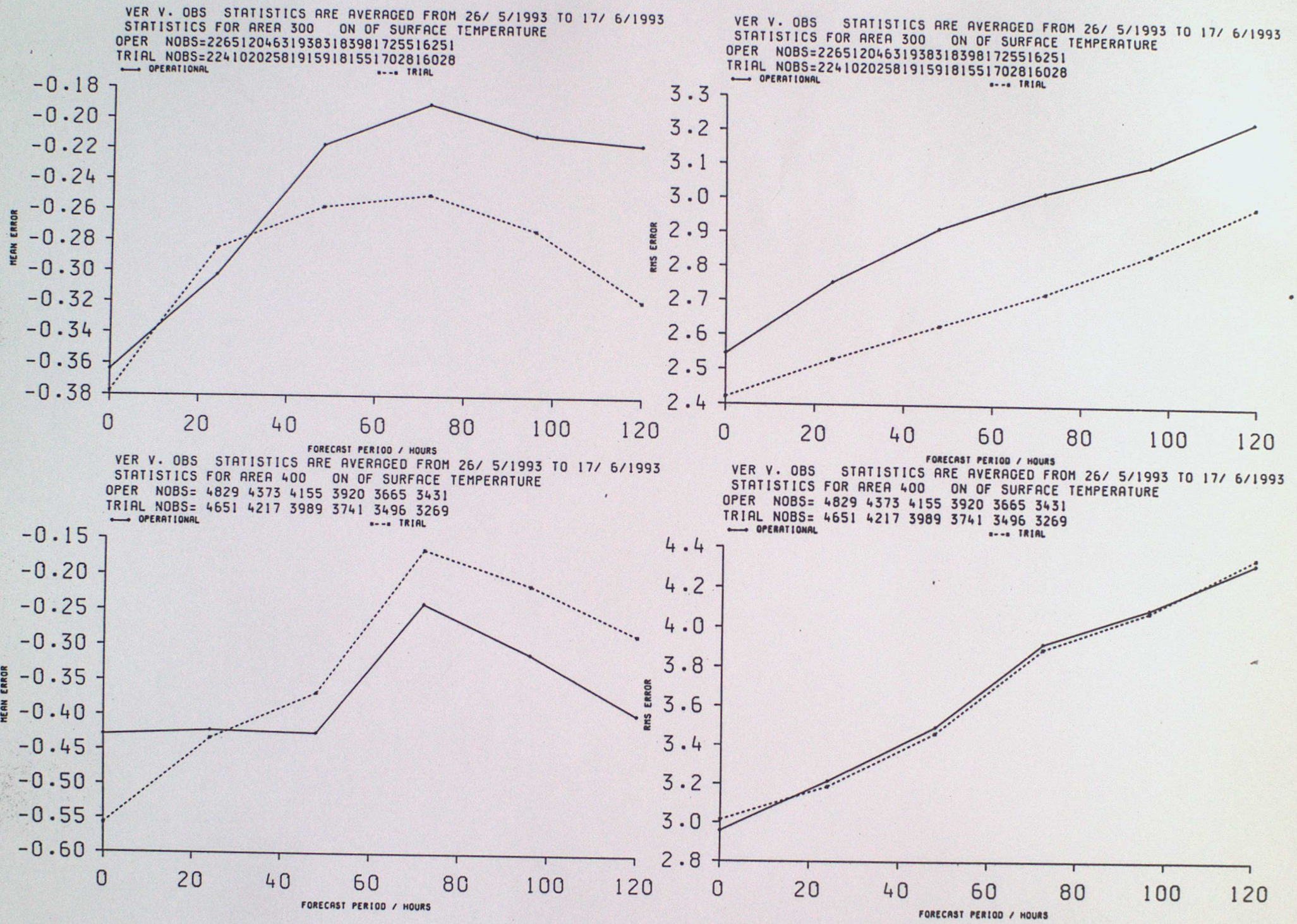

VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 300 ON OF SURFACE TEMPERATURE
OPER NOBS=2265120463193831839817255162 51
TRIAL NOBS=2241020258191591815517028160 28
OPERATIONAL
TRIAL
MEAN ERROR
-0.18
-0.20
-0.22
-0.24
-0.26
-0.28
-0.30
-0.32
-0.34
-0.36
-0.38
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 300 ON OF SURFACE TEMPERATURE
OPER NOBS=2265120463193831839817255162 51
TRIAL NOBS=2241020258191591815517028160 28
OPERATIONAL
TRIAL
RMS ERROR
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 400 ON OF SURFACE TEMPERATURE
OPER NOBS= 4829 4373 4155 3920 3665 3431
TRIAL NOBS= 4651 4217 3989 3741 3496 3269
OPERATIONAL
TRIAL
MEAN ERROR
-0.15
-0.20
-0.25
-0.30
-0.35
-0.40
-0.45
-0.50
-0.55
-0.60
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS
VER V. OBS STATISTICS ARE AVERAGED FROM 26/ 5/1993 TO 17/ 6/1993
STATISTICS FOR AREA 400 ON OF SURFACE TEMPERATURE
OPER NOBS= 4829 4373 4155 3920 3665 3431
TRIAL NOBS= 4651 4217 3989 3741 3496 3269
OPERATIONAL
TRIAL
RMS ERROR
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
0
20
40
60
80
100
120
FORECAST PERIOD / HOURS

Fig 4.14

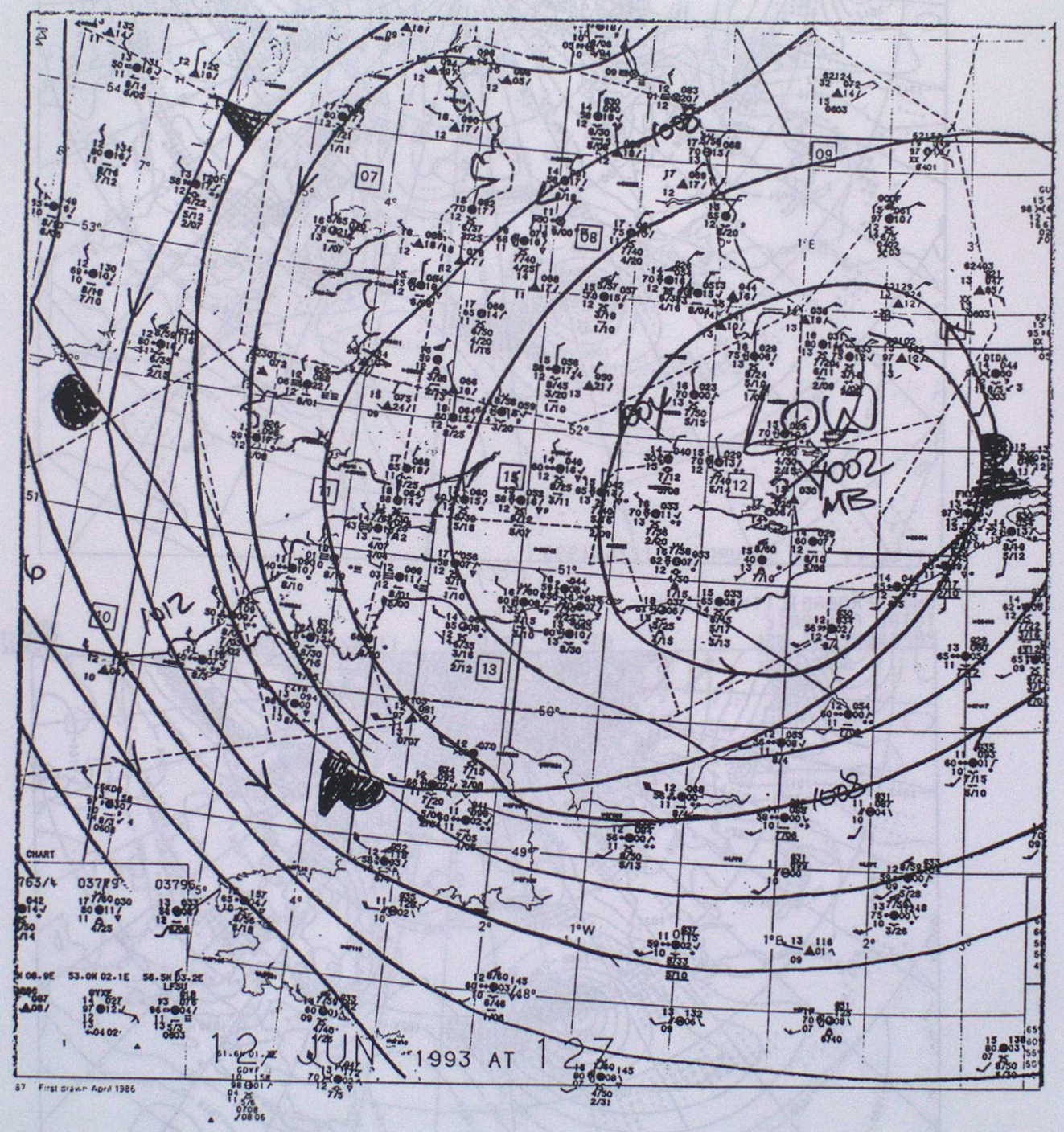
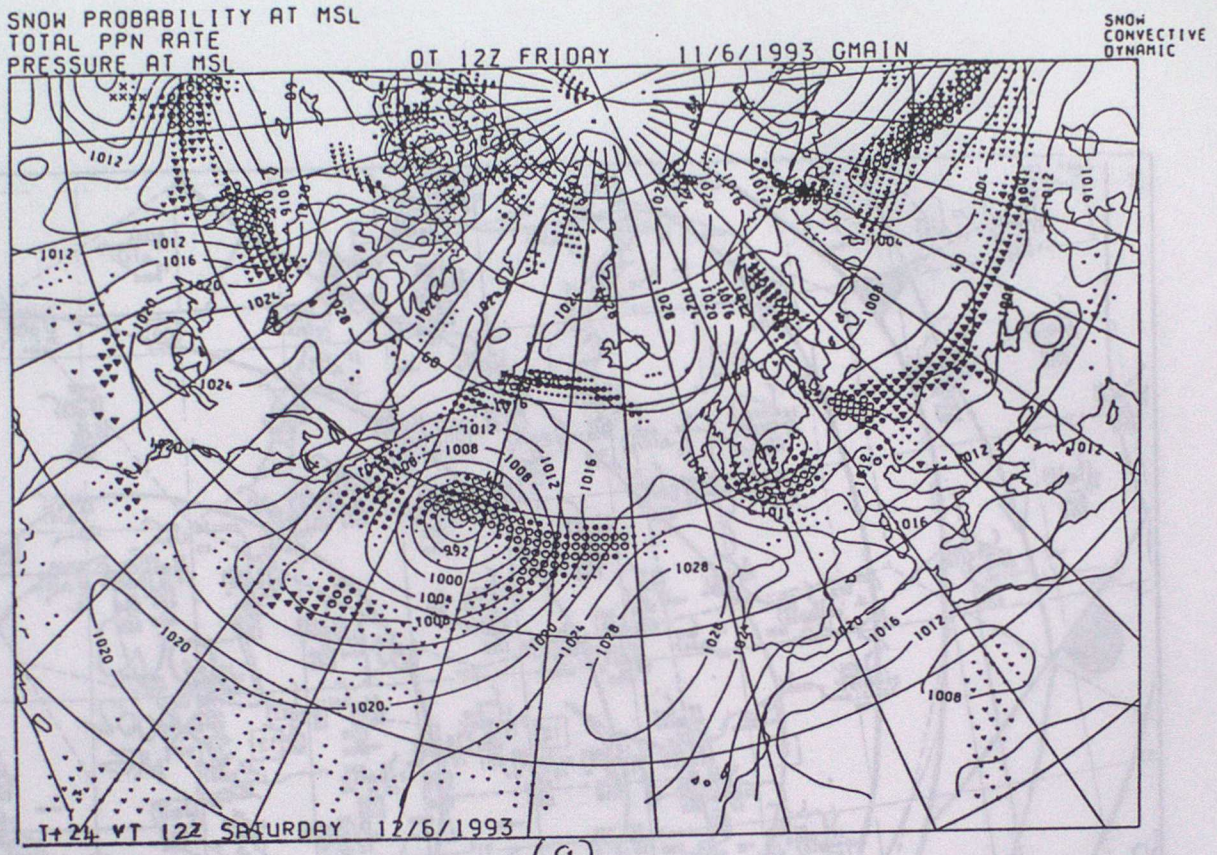
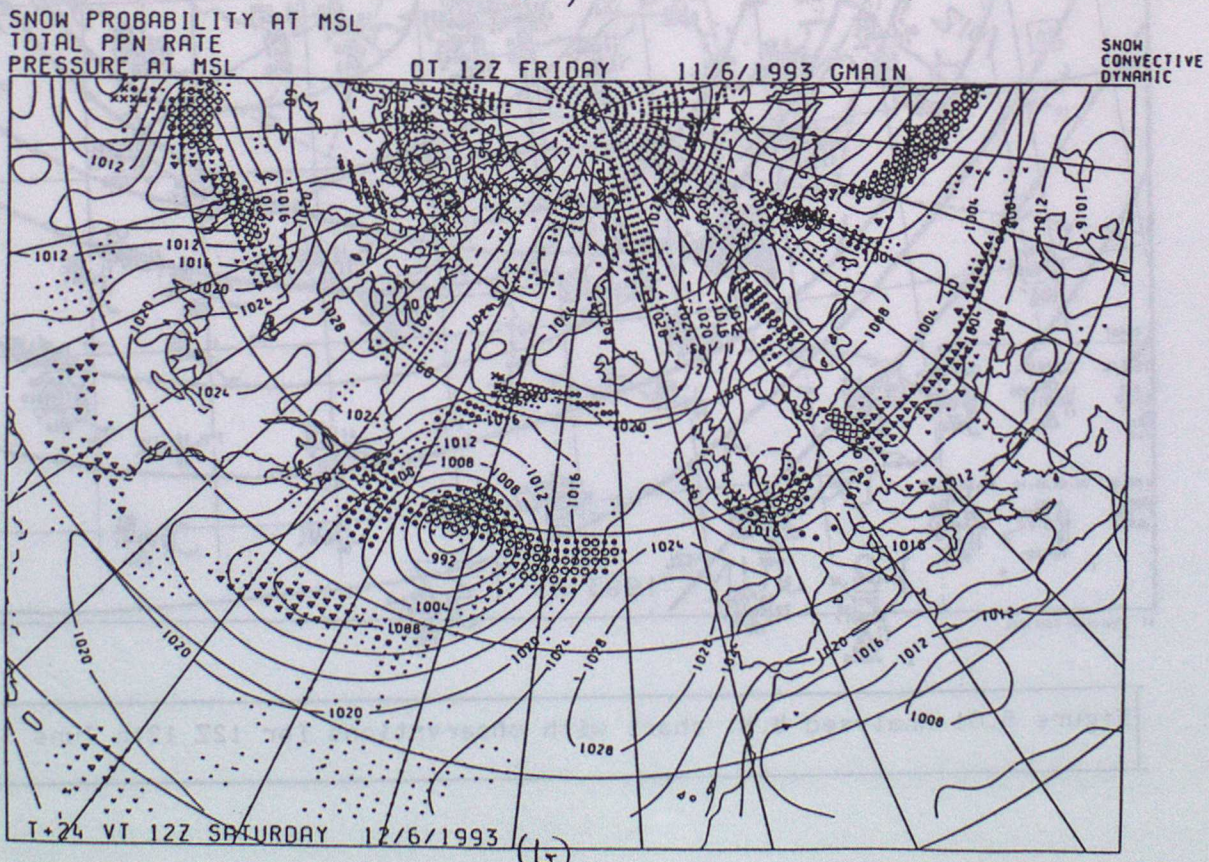


Figure 5.01 Analysed U.K. chart with observations for 12Z 12th June 1993

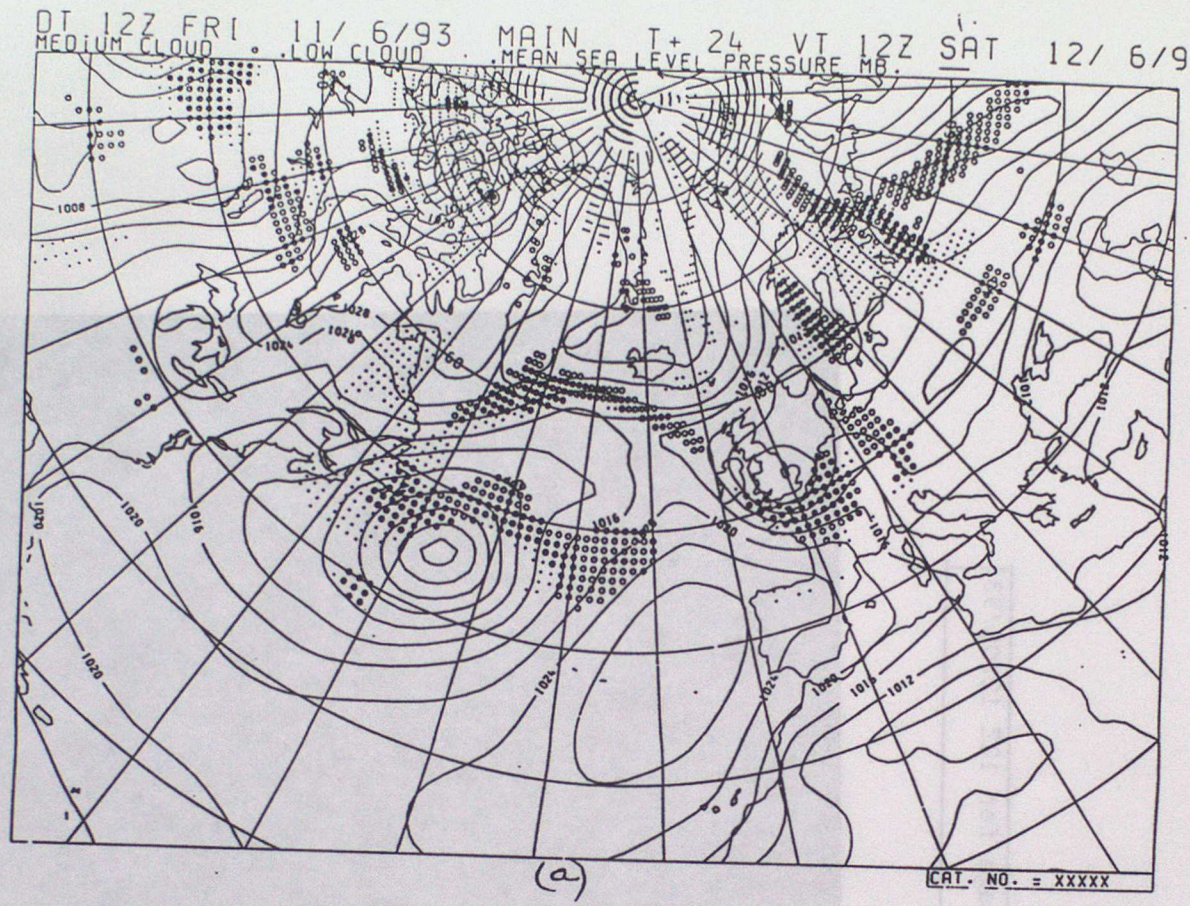


(a)

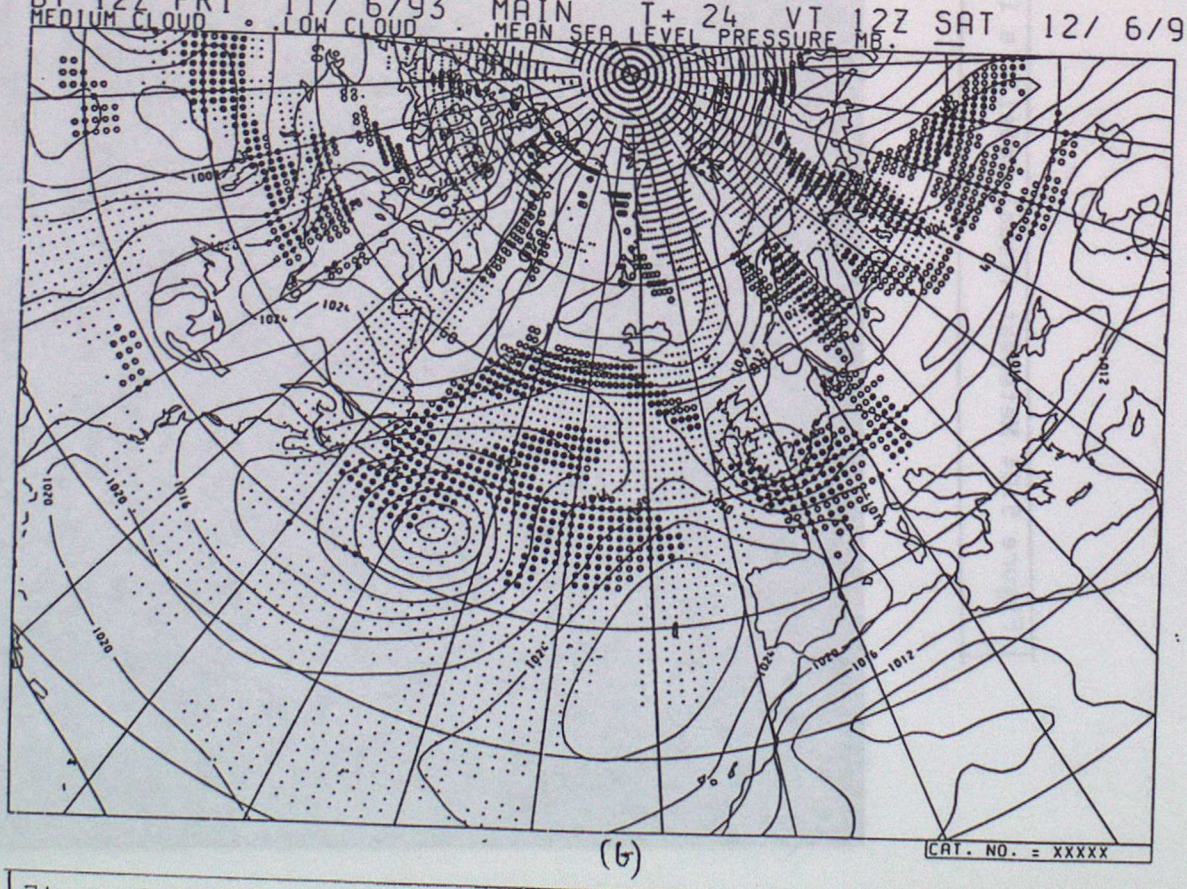


(b)

Figure 5.02a T+24 f/c vt 12Z 12/06/93 - Trial(frozen physics package)
Figure 5.02b T+24 f/c vt 12Z 12/06/93 - Operational



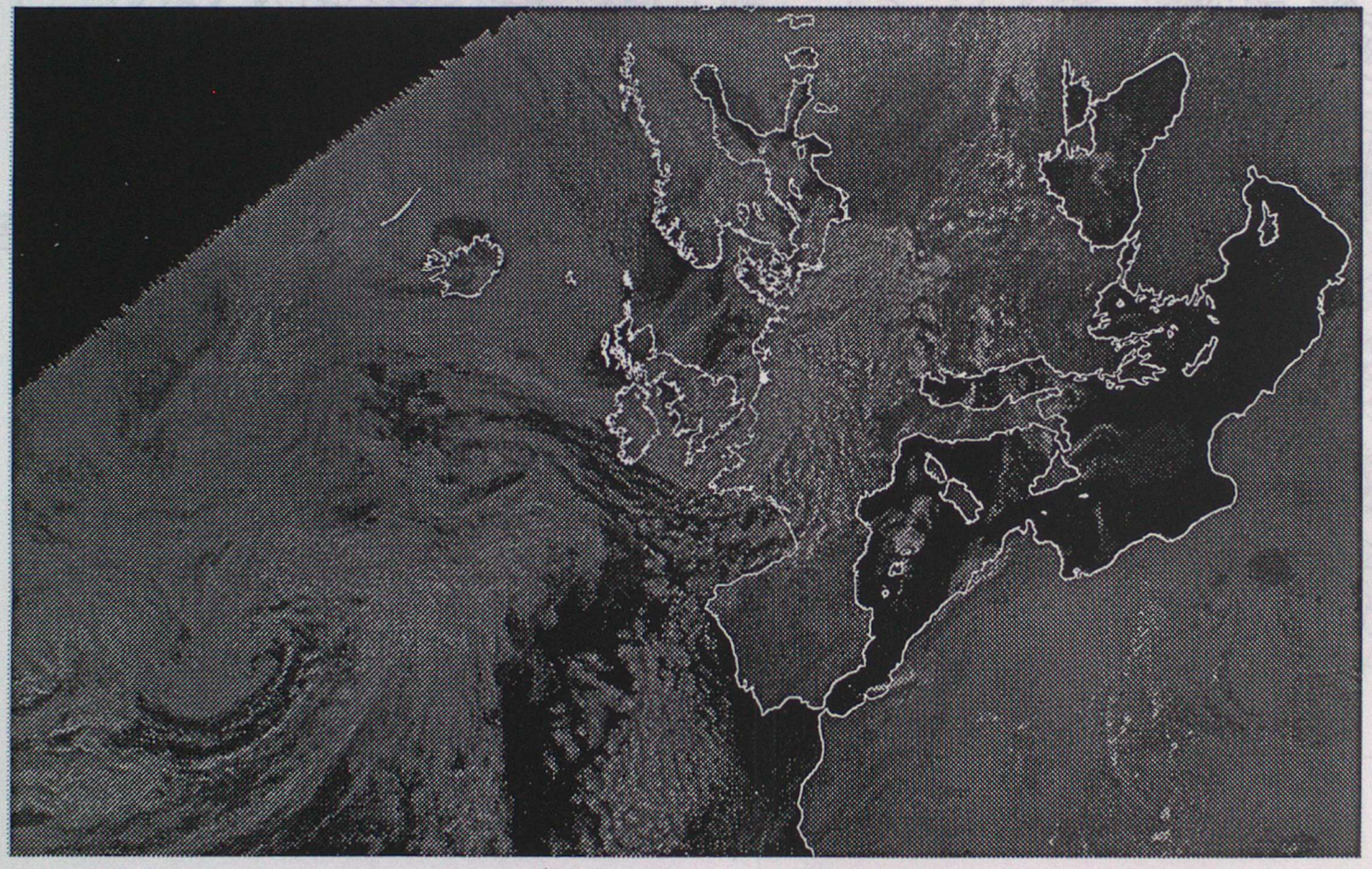
(a)



(b)

Figure 5.03a T+24 f/c vt 12Z 12/06/93 - Trial(frozen physics package)
(low and medium cloud layers (> 4 octas)
Figure 5.03b T+24 f/c vt 12Z 12/06/93 - Operational
(low and medium cloud layers (> 4 octas)

Figure 5.04 Meteosat visual satellite image for 12Z 12/06/93



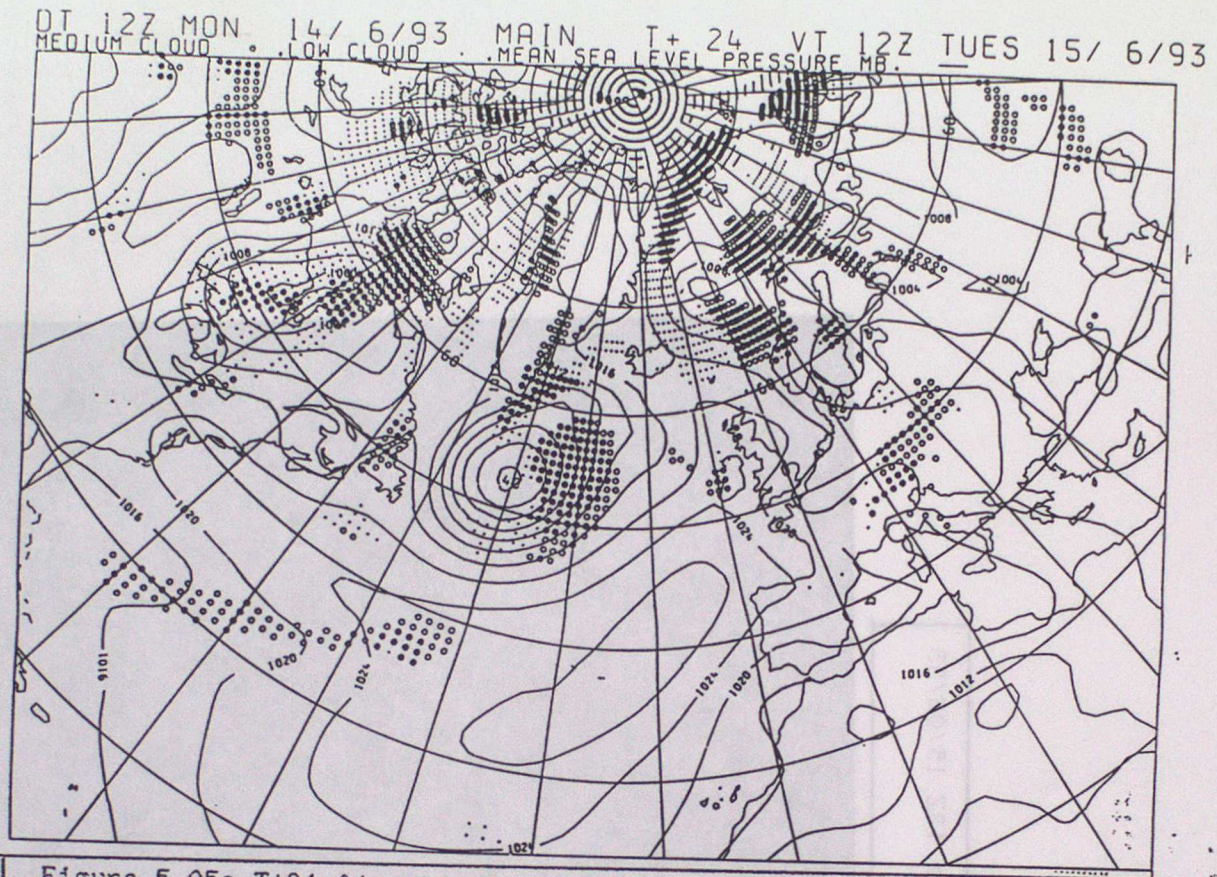


Figure 5.05a T+24 f/c vt 12Z 15/06/93 - Trial (frozen physics package)
(low and medium cloud layers ( ) 4 octas)

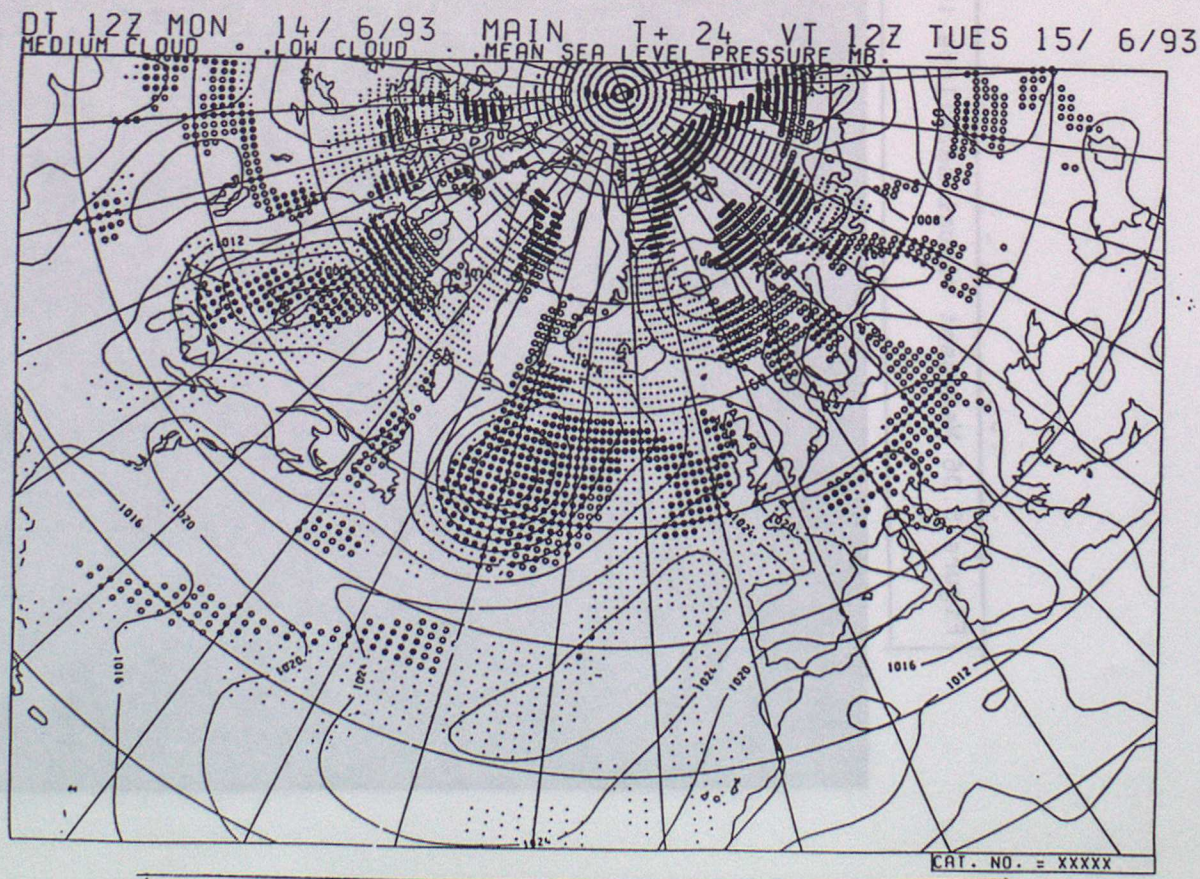


Figure 5.05b T+24 f/c vt 12Z 15/06/93 - Operational
(low and medium cloud layers ( ) 4 octas)

Figure 5.06 Meteosat visual satellite image for 12Z 15/06/93

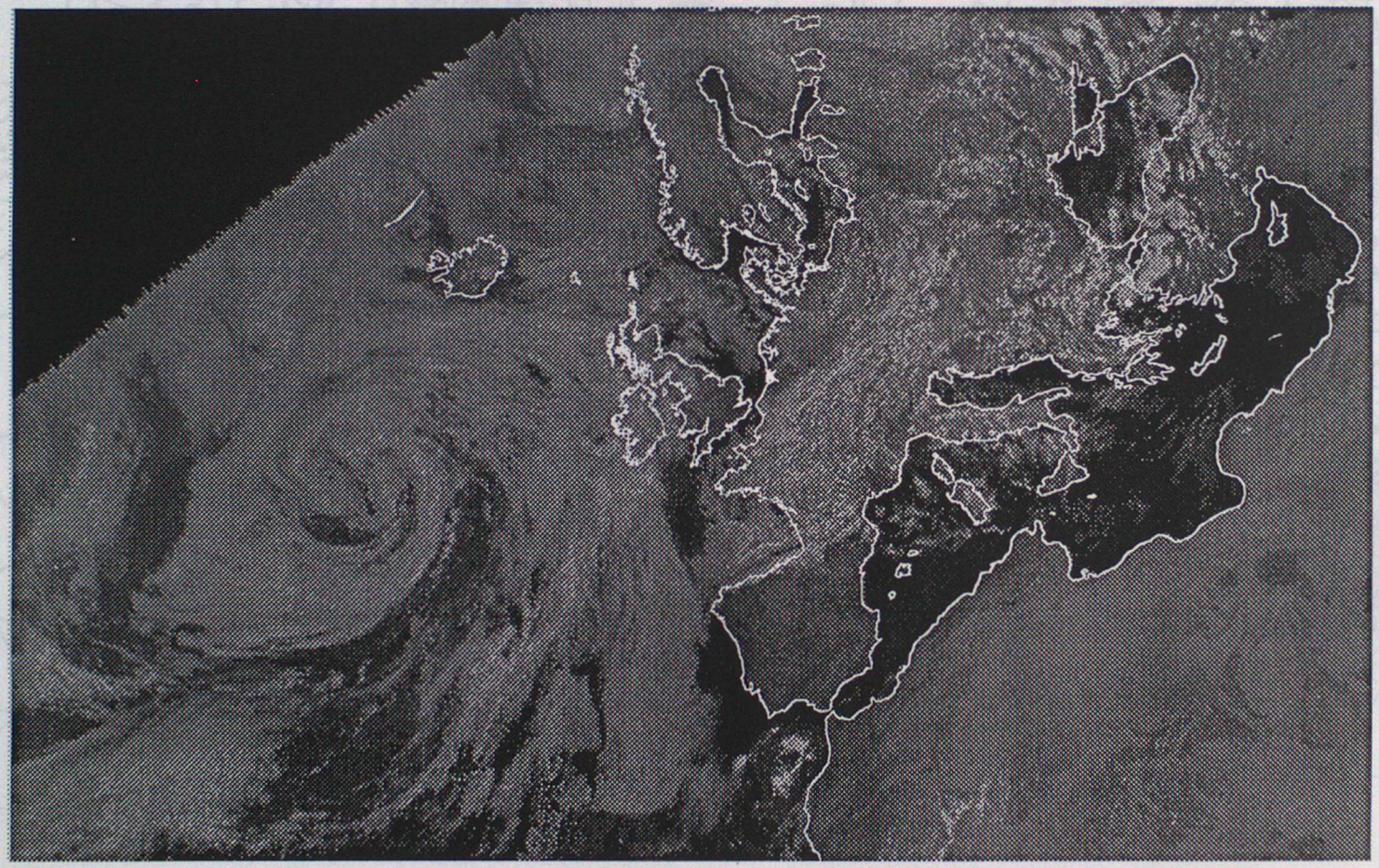
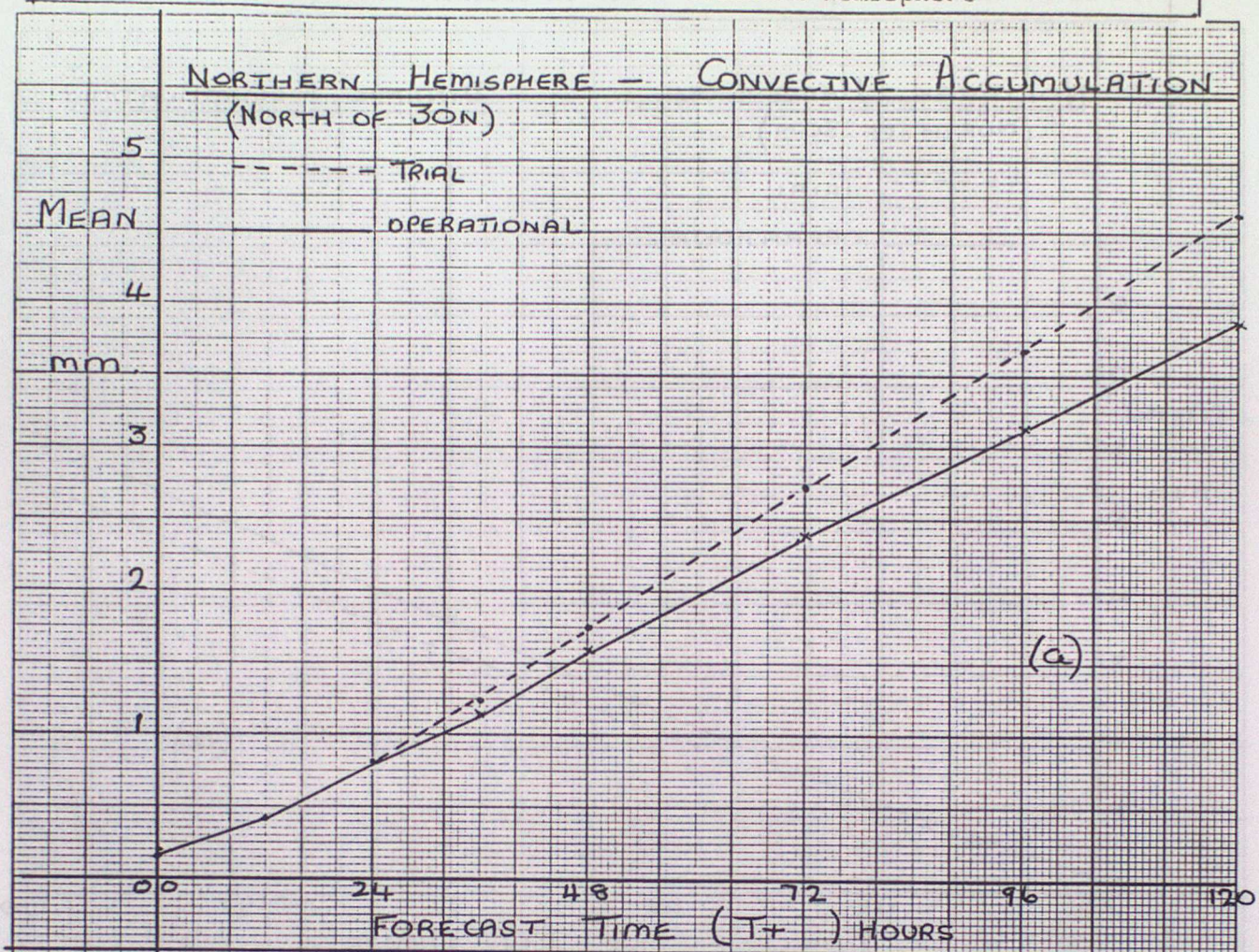


Figure 5.07 Graph showing the mean convective accumulation in mm per grid square during the forecast for the period DT 12Z 25/05/93-DT12Z 17/06/93
(a) in Northern Hemisphere (b) in Southern Hemisphere



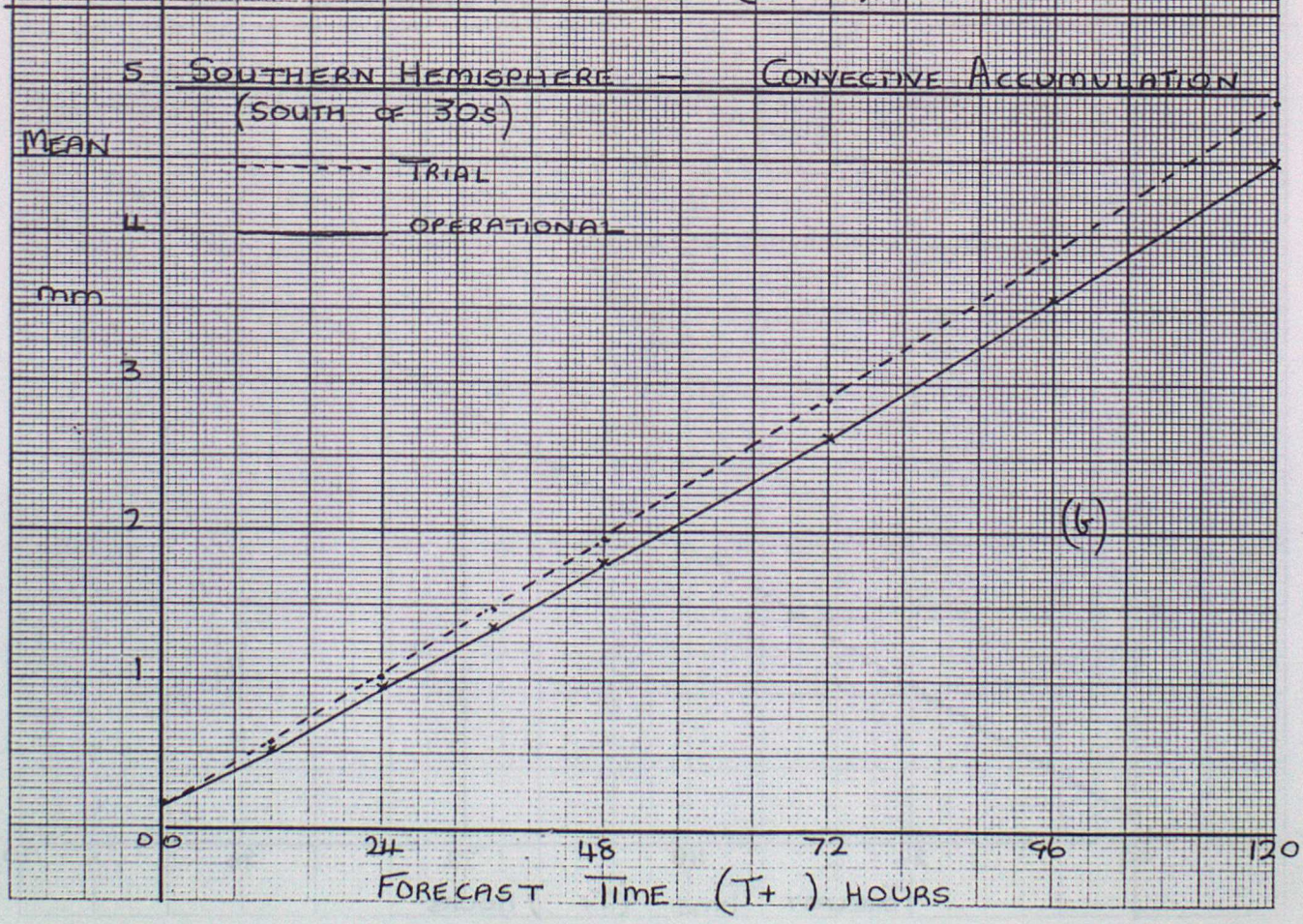
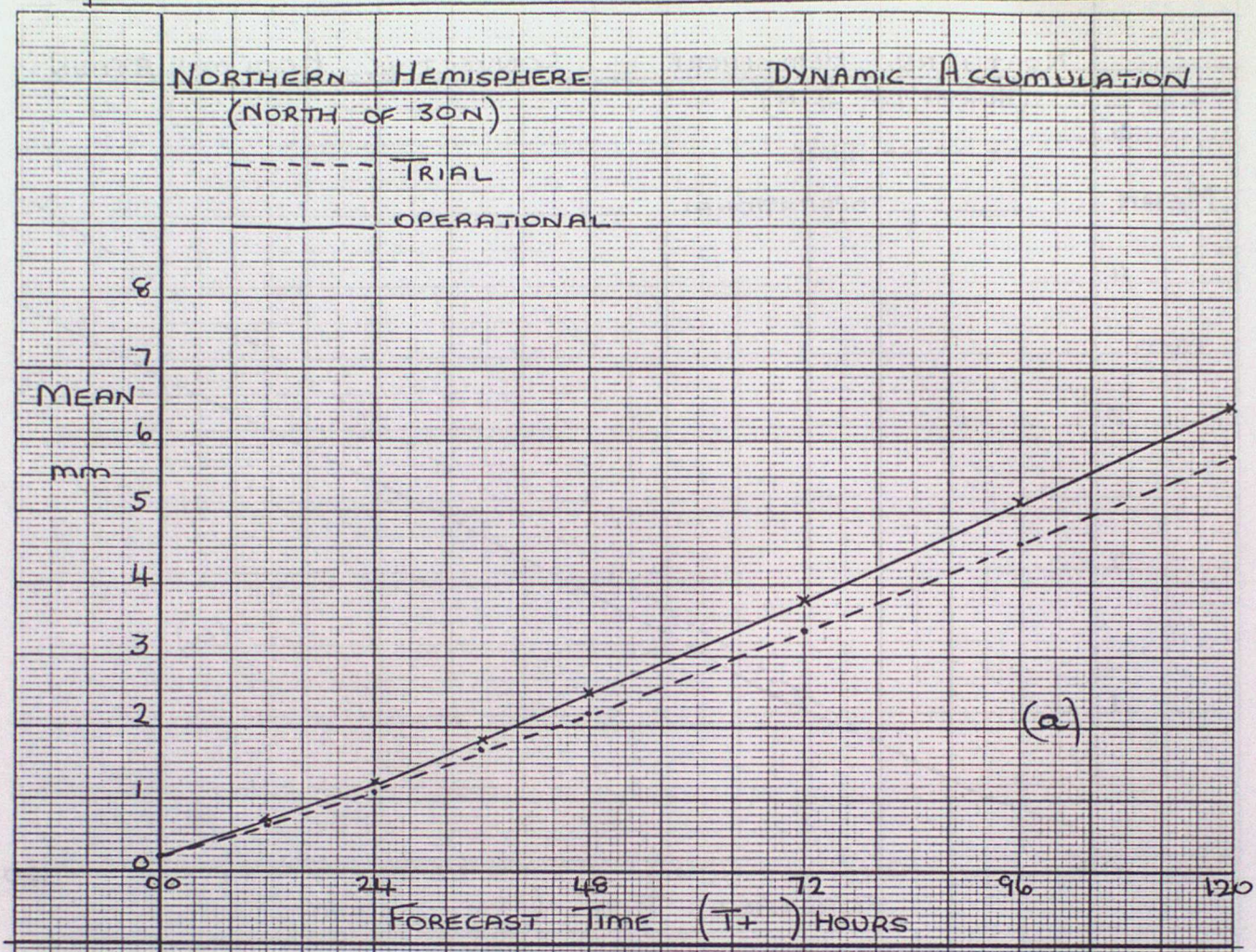


Figure 5.08 Graph showing the mean dynamic accumulation in mm per grid square during the forecast for the period DT 12Z 25/05/93-DT12Z 17/06/93
(a) in Northern Hemisphere (b) in Southern Hemisphere



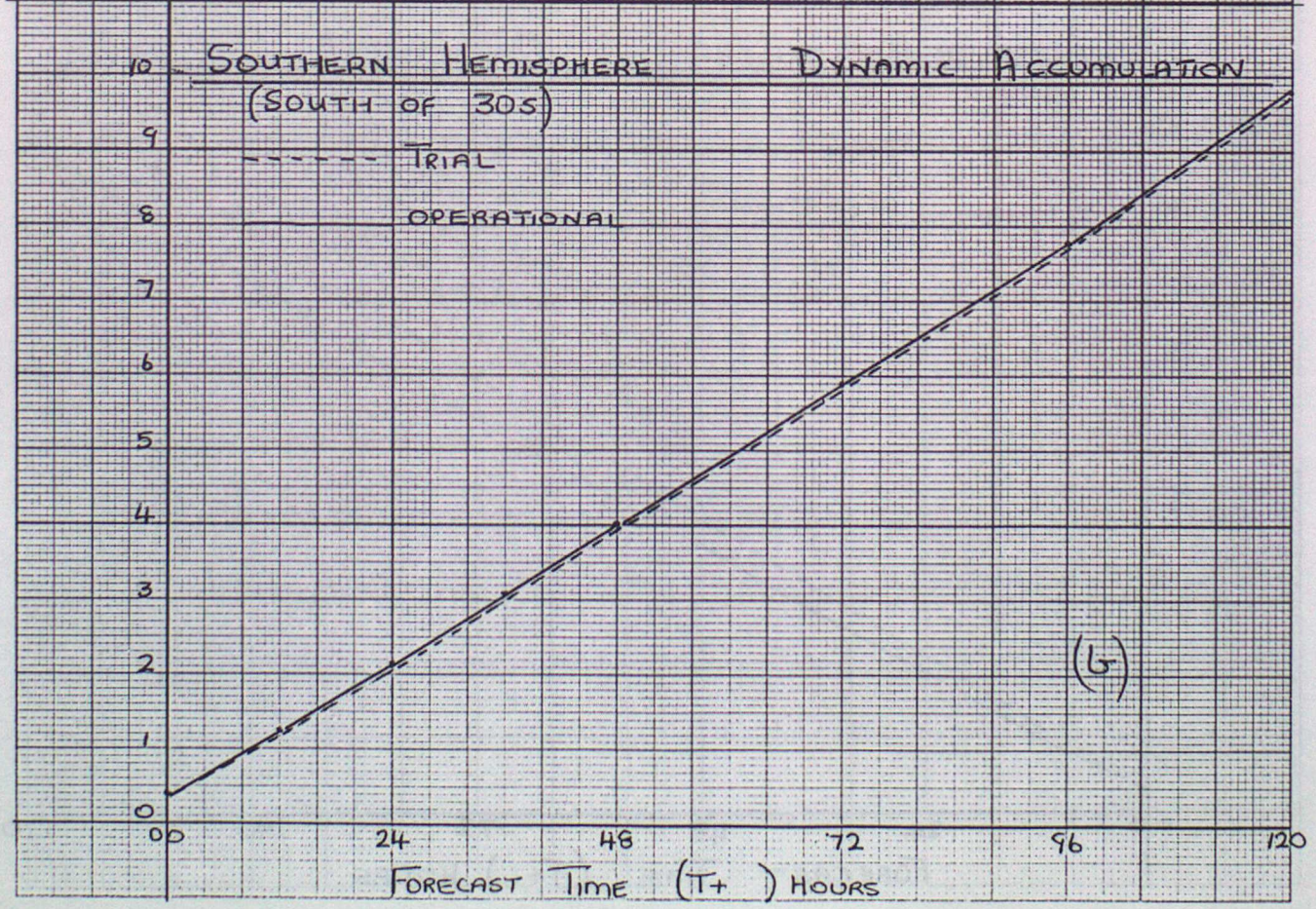
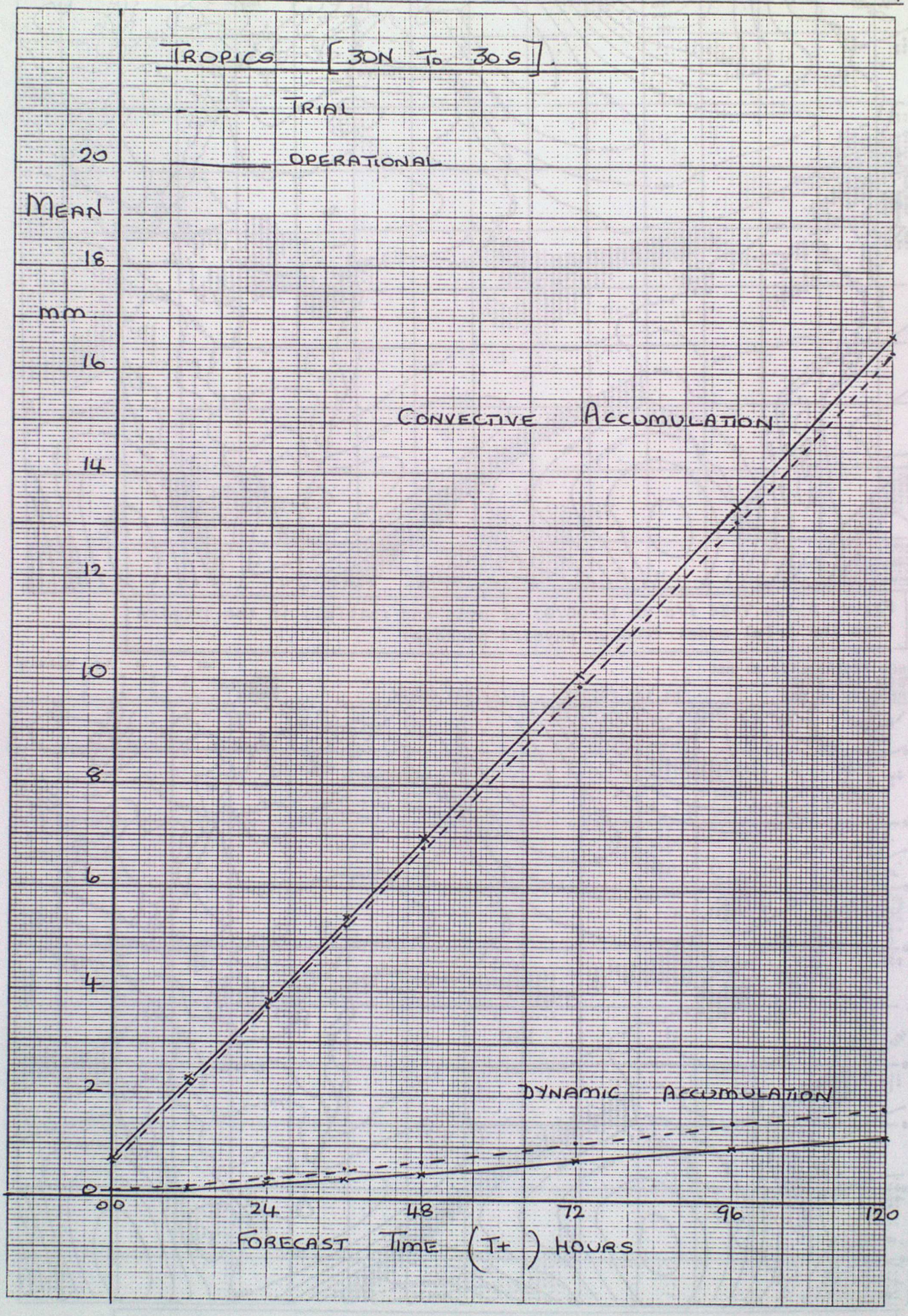


Figure 5.09 Graph showing the mean dynamic and convective accumulations in mm per grid square during the forecast for the period DT 12Z 25/05/93-DT12Z 17/06/93 for the Tropics



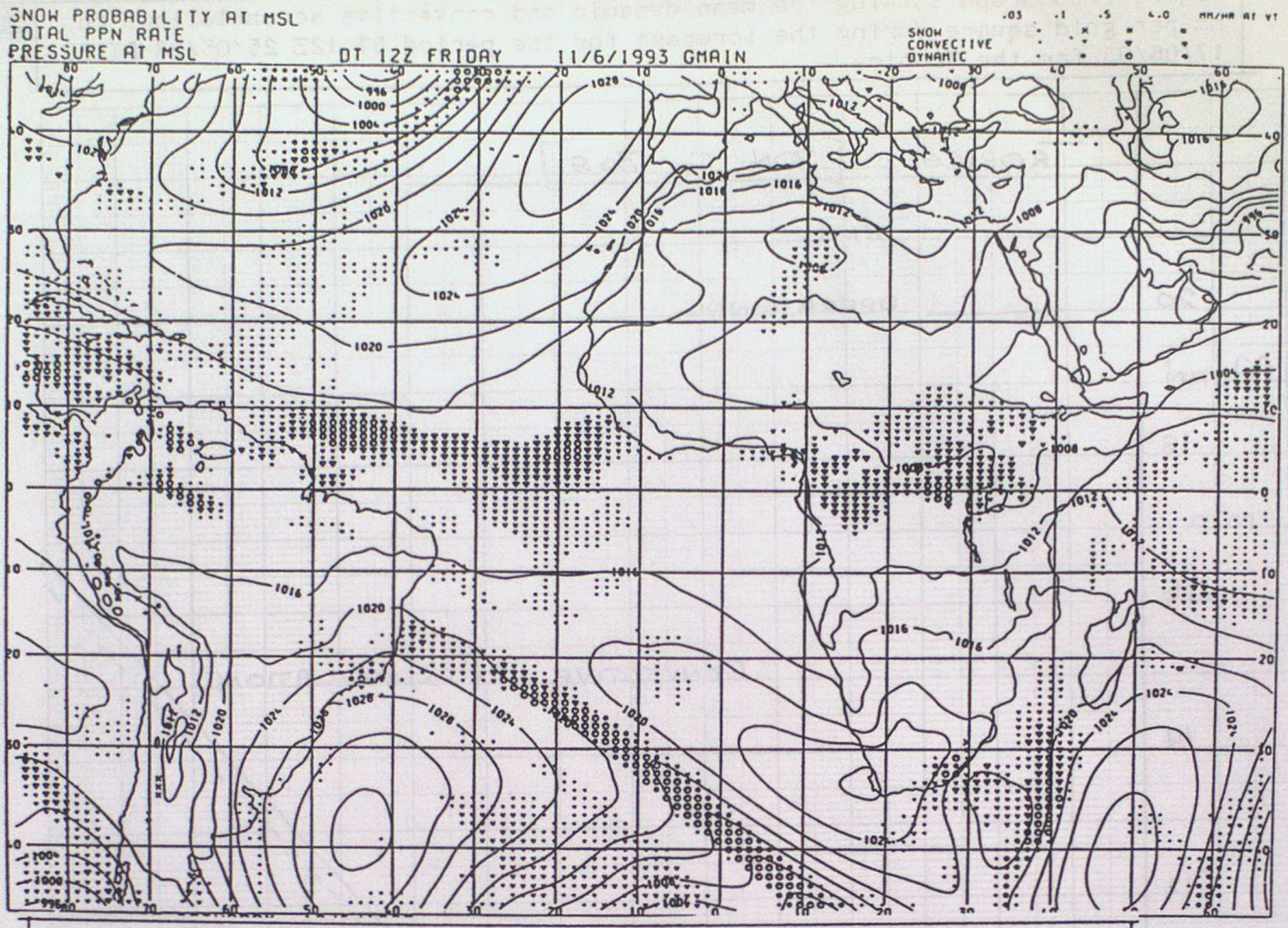


Figure 5.10a T+24 f/c vt 12/06/93 of mslp and rainfall in the Tropics from the trial model (frozen physics package)

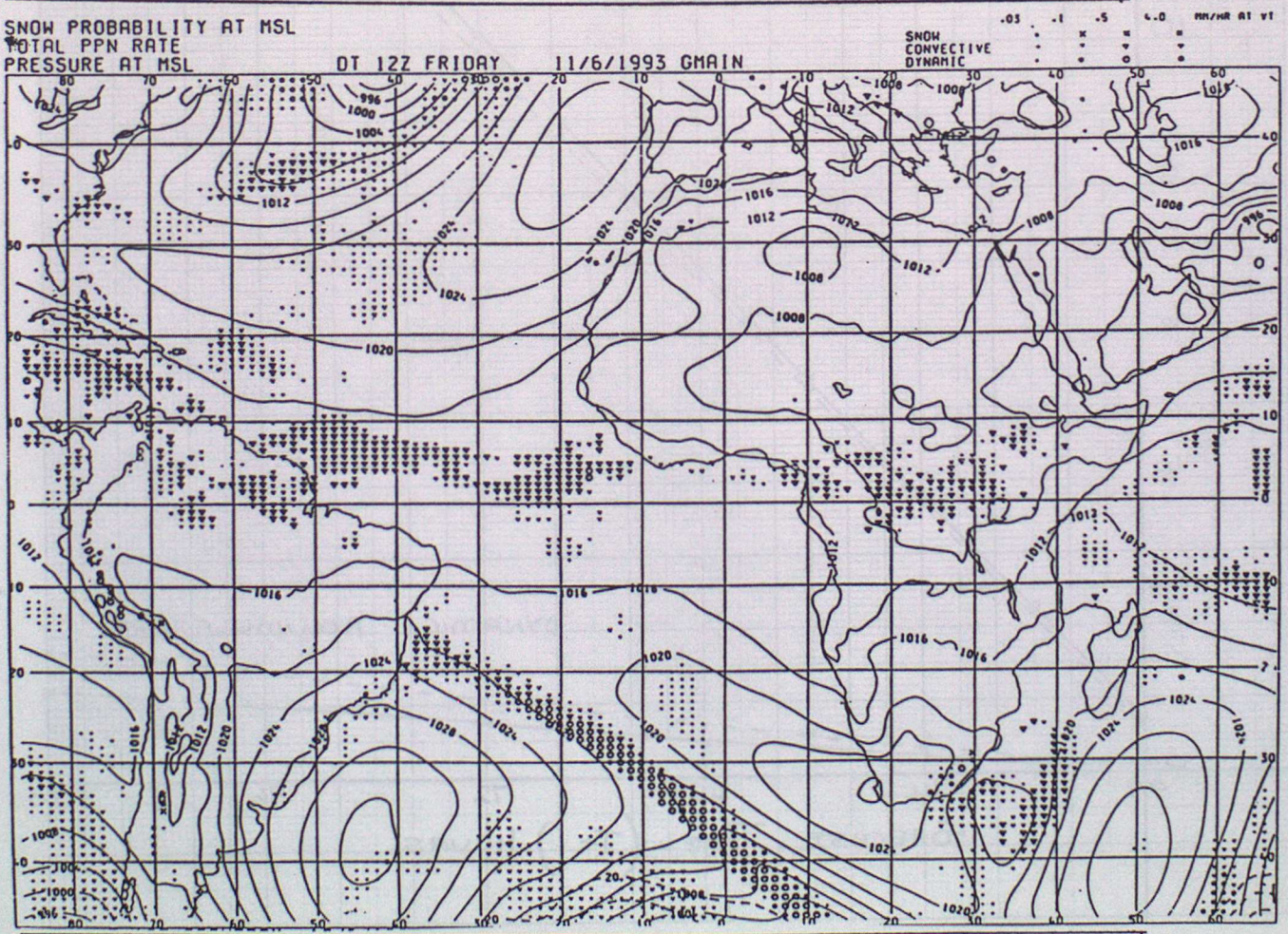


Figure 5.10b T+24 f/c vt 12/06/93 of mslp and rainfall in the Tropics from the operational model

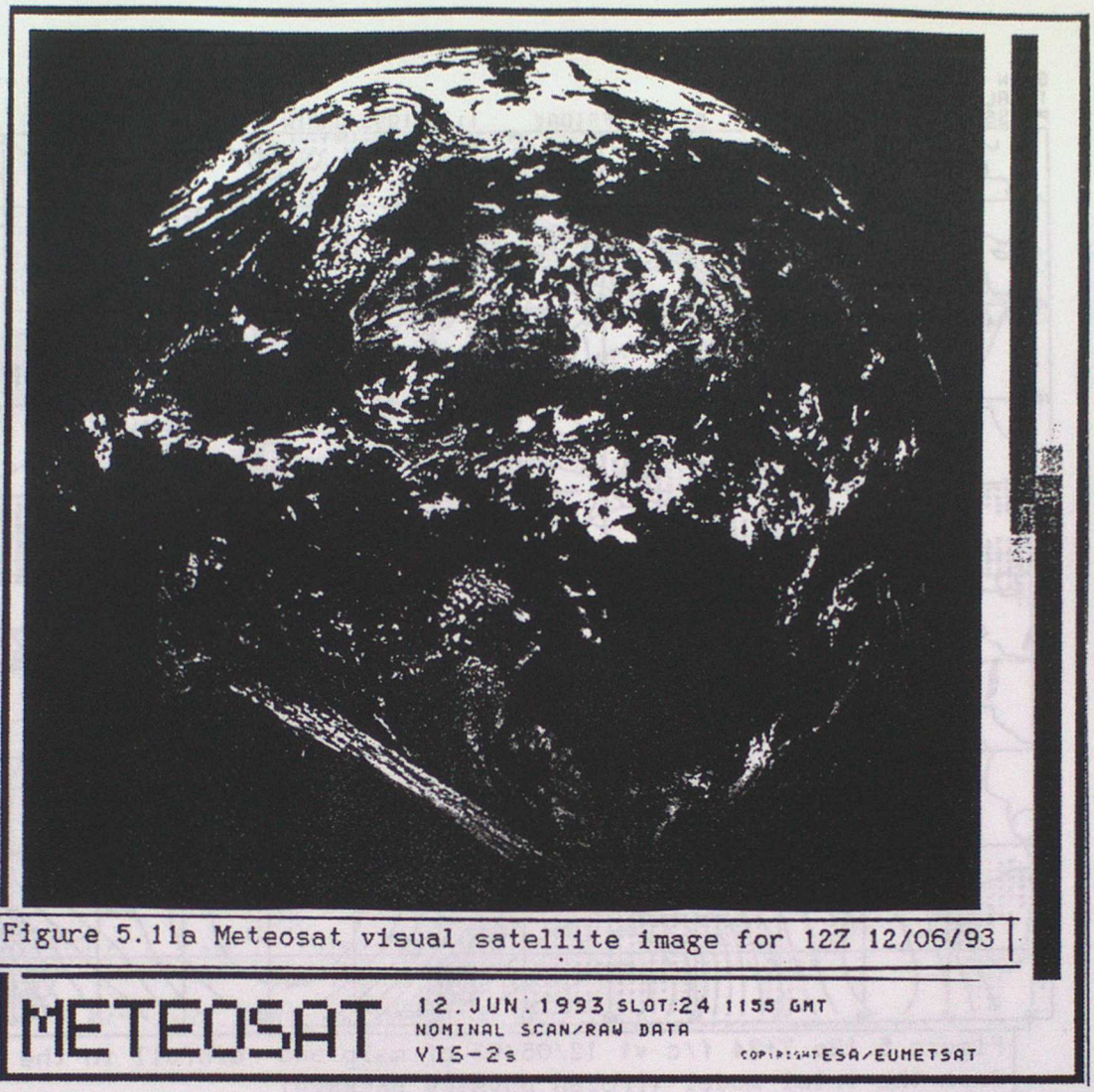


Figure 5.11a Meteosat visual satellite image for 12Z 12/06/93

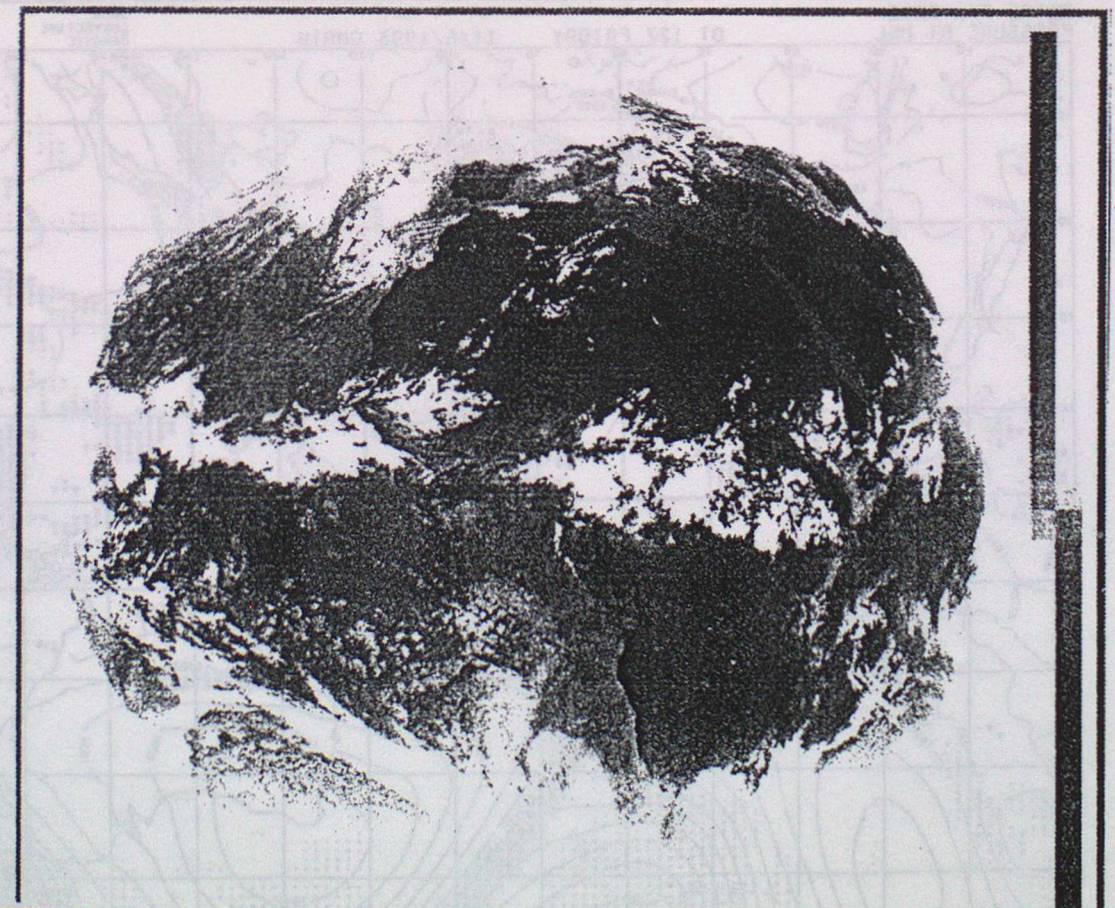


Figure 5.11b Meteosat infra red satellite image for 12Z 12/06/93

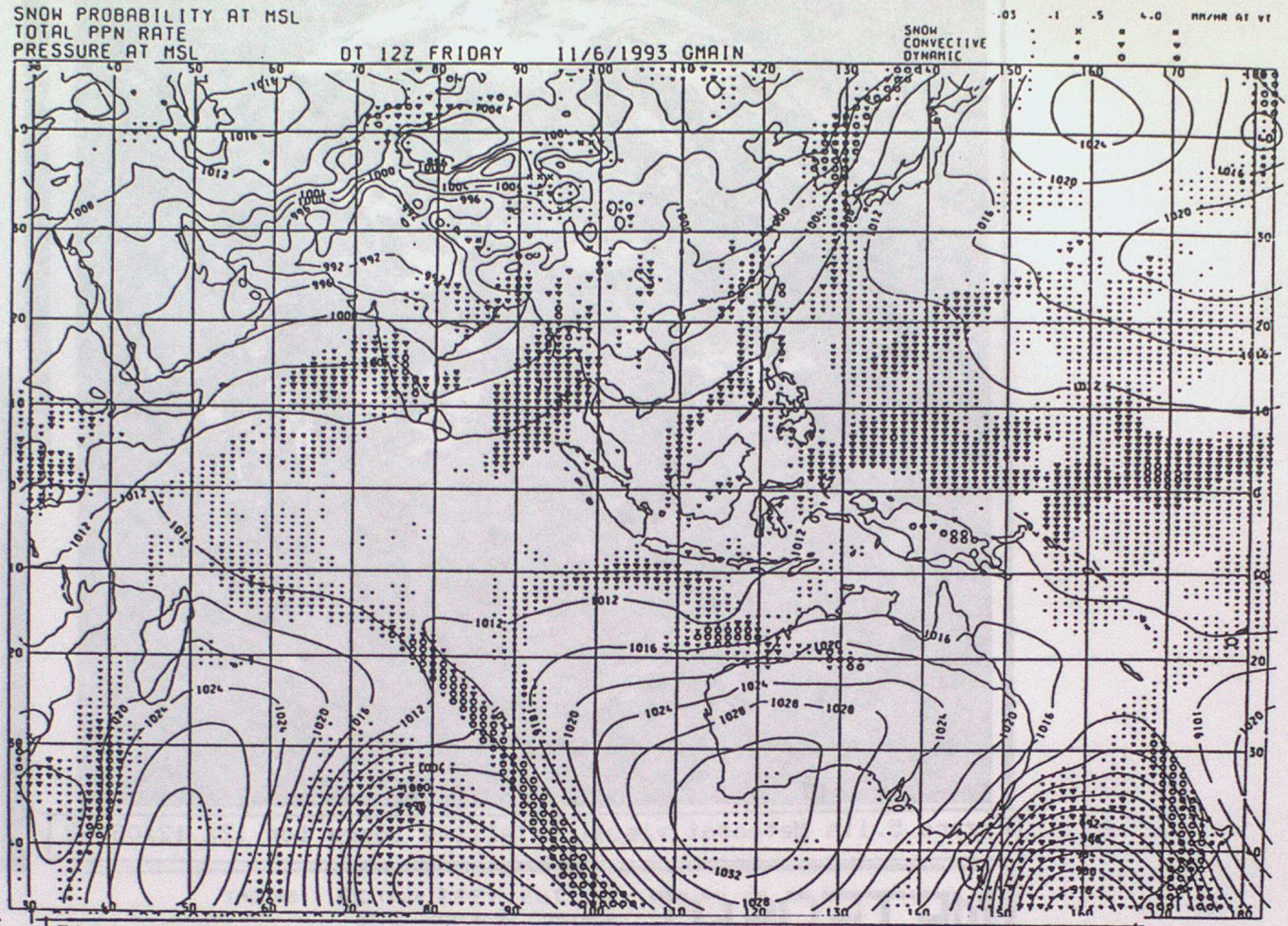


Figure 5.12a T+24 f/c vt 12/06/93 of mslp and rainfall in the Tropics from the trial model (frozen physics package)

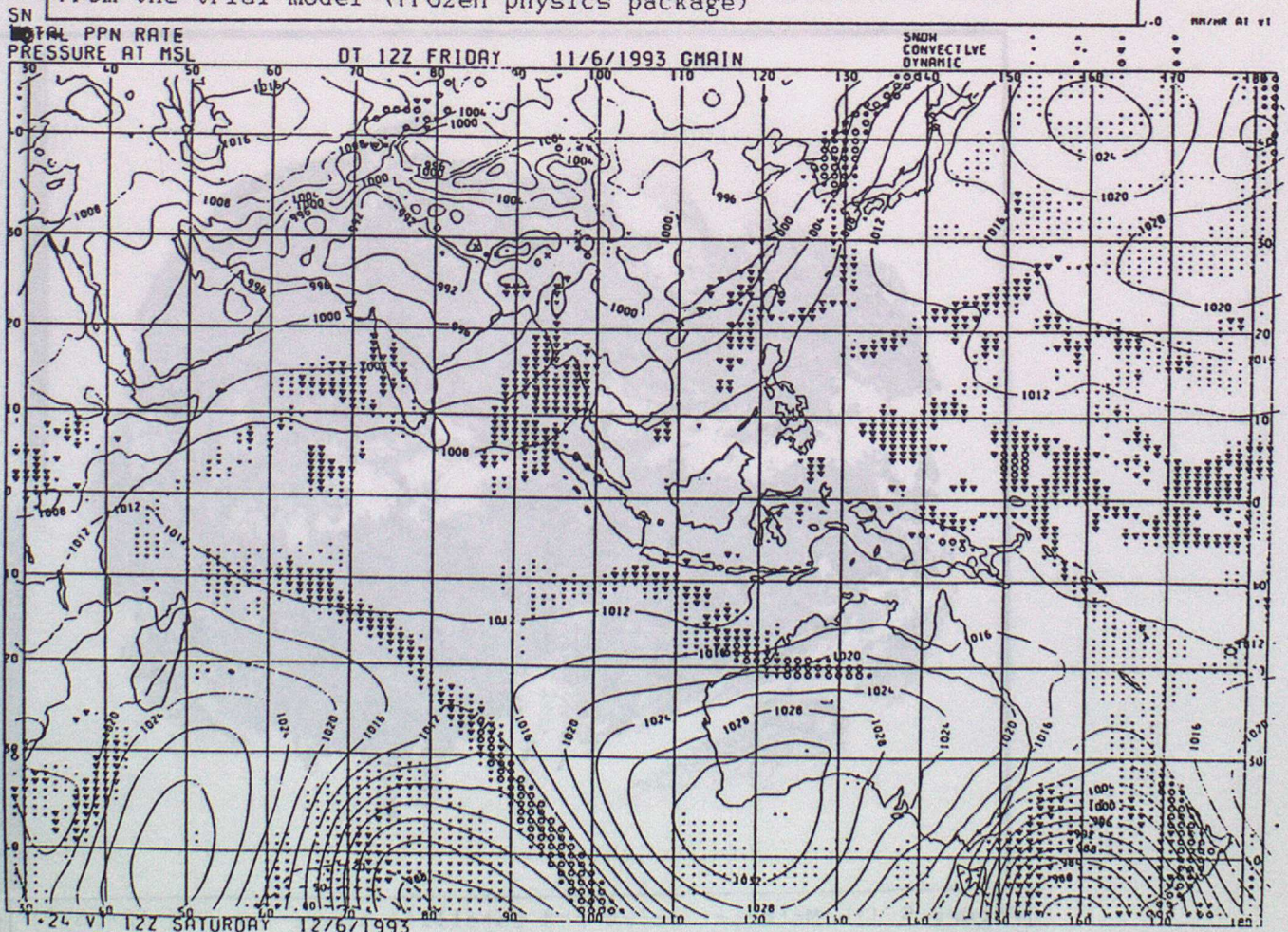


Figure 5.12b T+24 f/c vt 12/06/93 of mslp and rainfall in the Tropics from the operational model

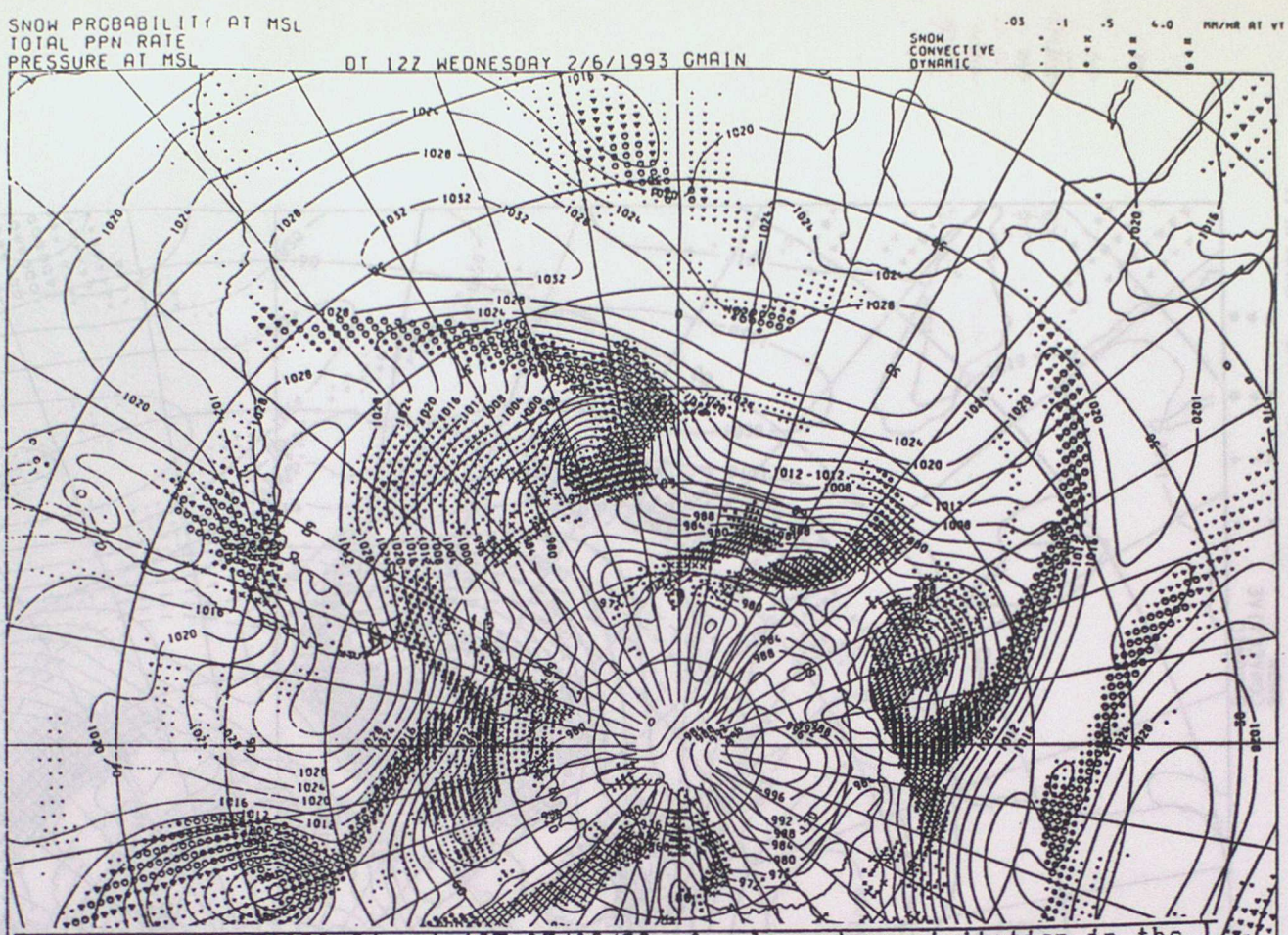


Figure 5.13a T+120 f/c vt 12Z 07/06/93 of mslp and precipitation in the Southern Hemisphere from the trial model (frozen physics package)

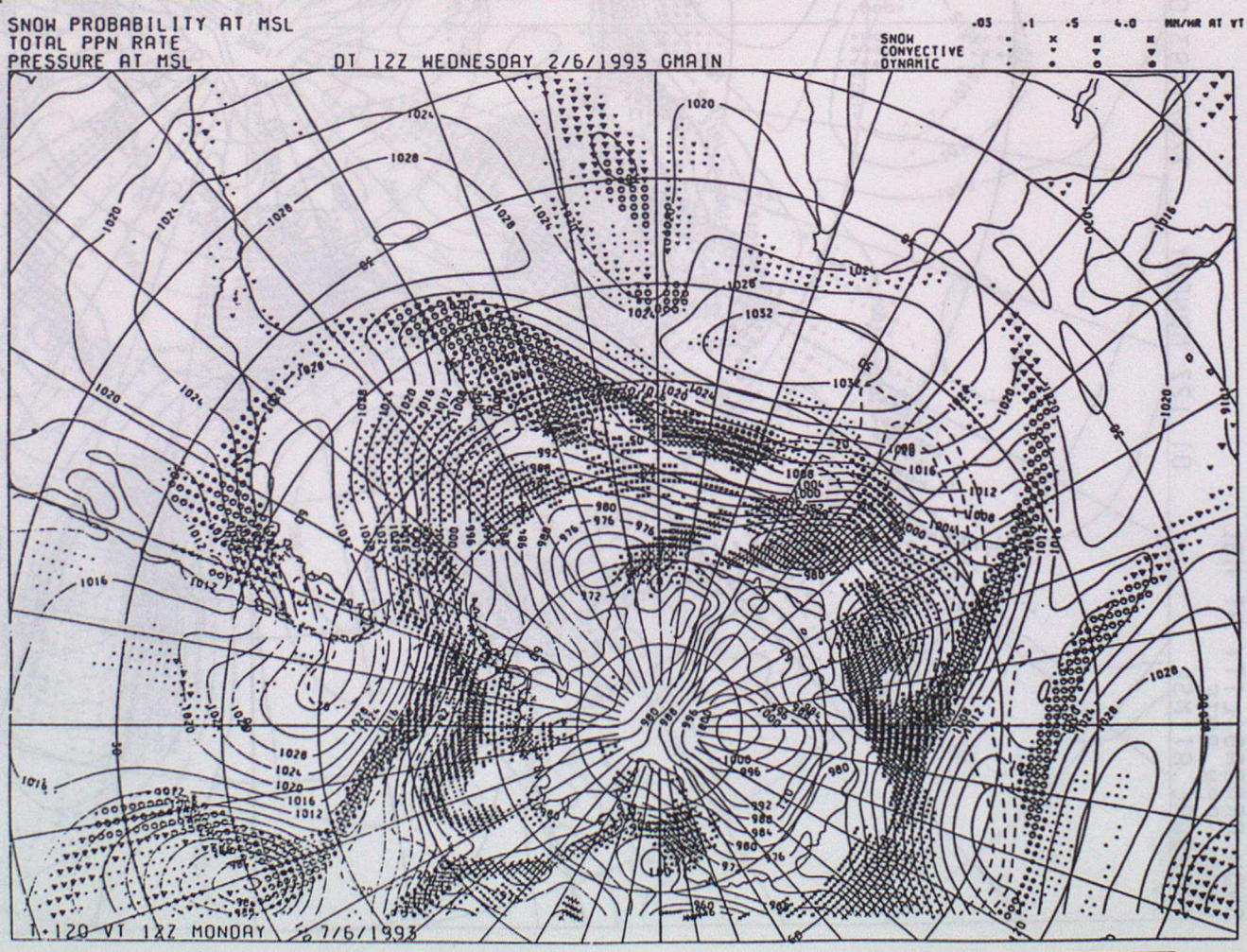


Figure 5.13b T+120 f/c vt 12Z 07/06/93 of mslp and precipitation in the Southern Hemisphere from the operational model

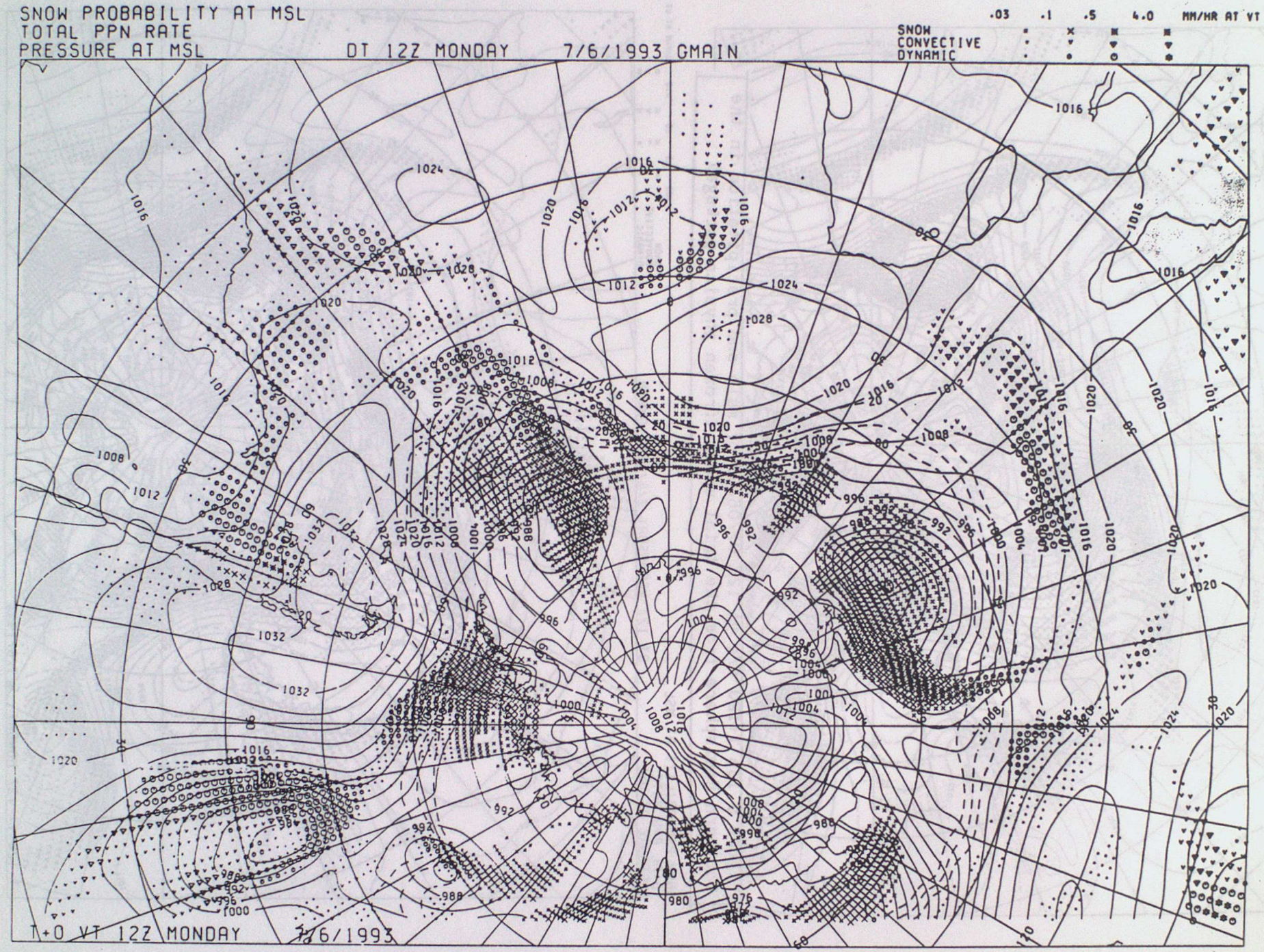


Figure 5.14 Operational mslp analysis for 12Z 07/06/93 in the Southern Hemisphere

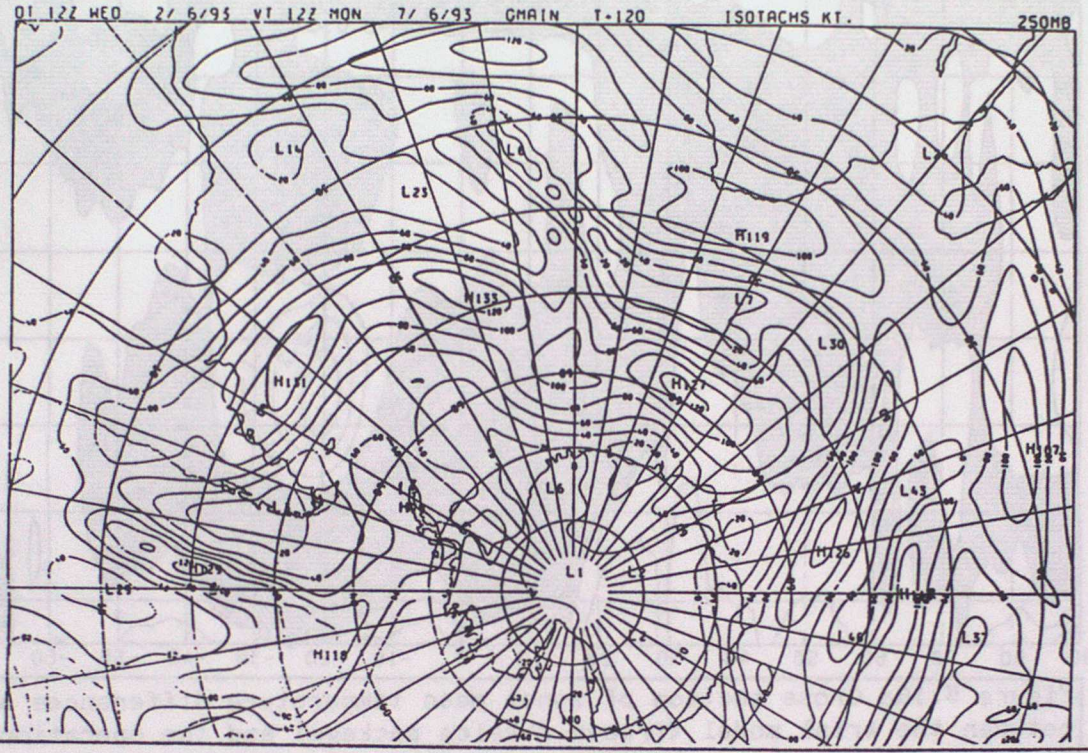


Figure 5.15a T+120 f/c vt 12Z 07/06/93 of 250mb wind isotachs in the Southern Hemisphere from the trial model (frozen physics package)

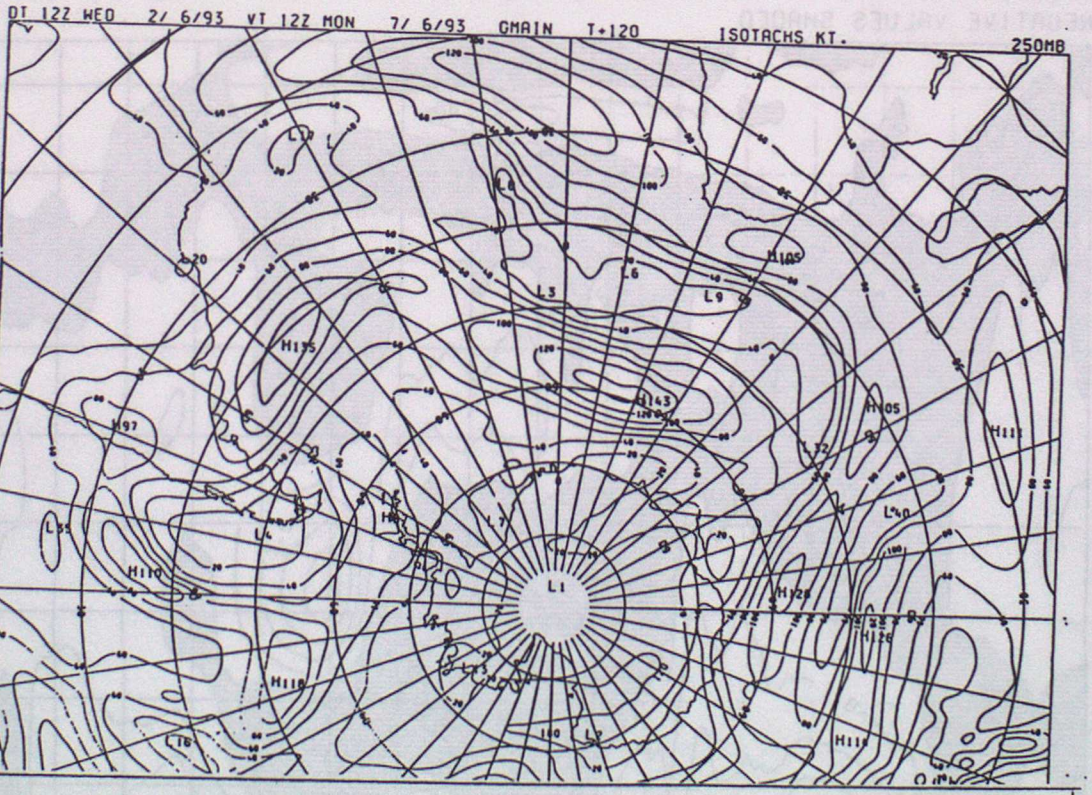


Figure 5.15b T+120 f/c vt 12Z 07/06/93 of 250mb wind isotachs in the Southern Hemisphere from the operational model

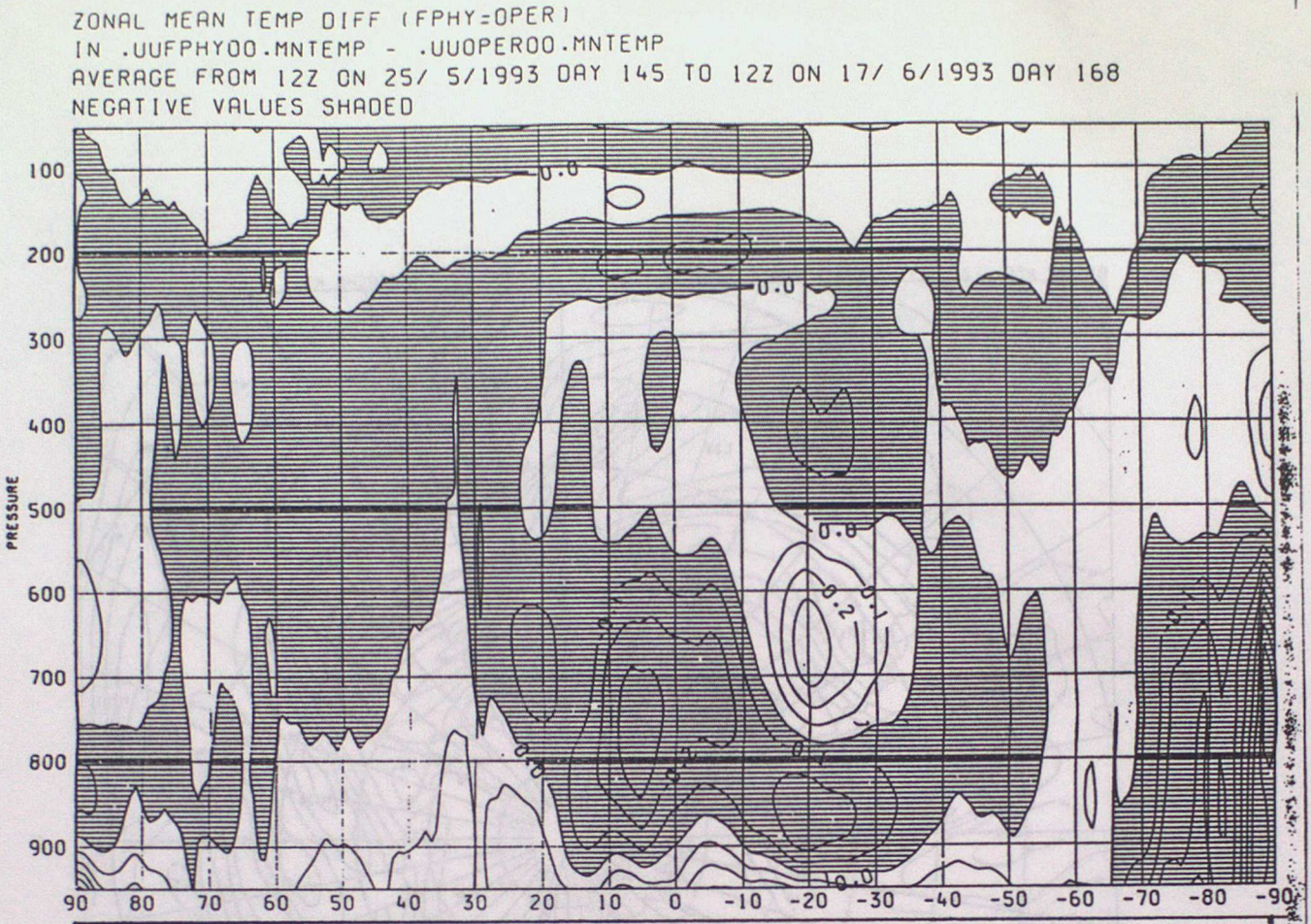


Figure 5.16a Cross section of zonal mean temperature differences at T+00 between the trial model (frozen physics package) and the operational model (trial-oper) for the period 12Z 25/05/93 to 12Z 17/06/92

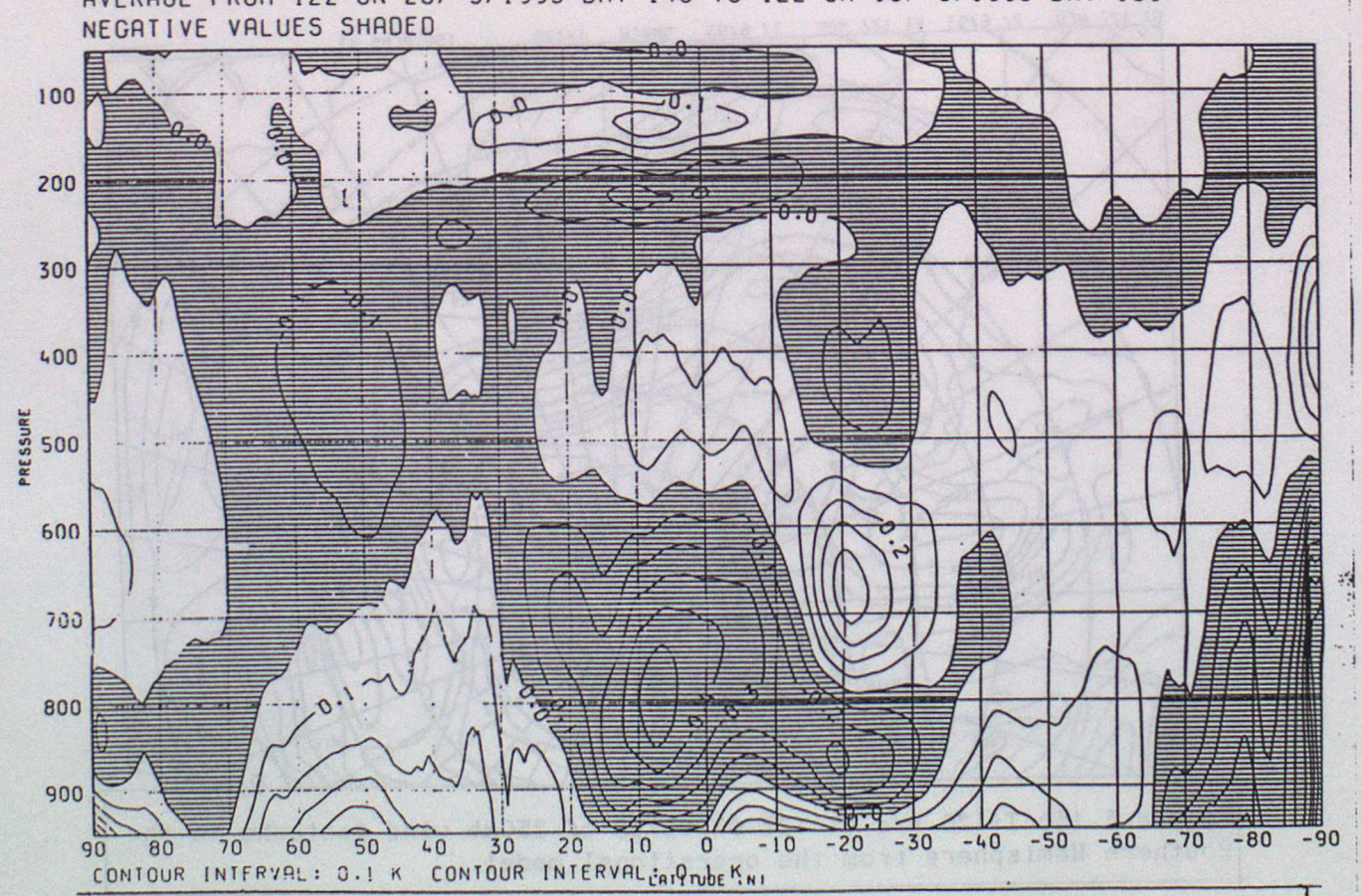


Figure 5.16b Cross section of zonal mean temperature differences at T+24 between the trial model (frozen physics package) and the operational model (trial-oper) for the period 12Z 26/05/93 to 12Z 18/06/92

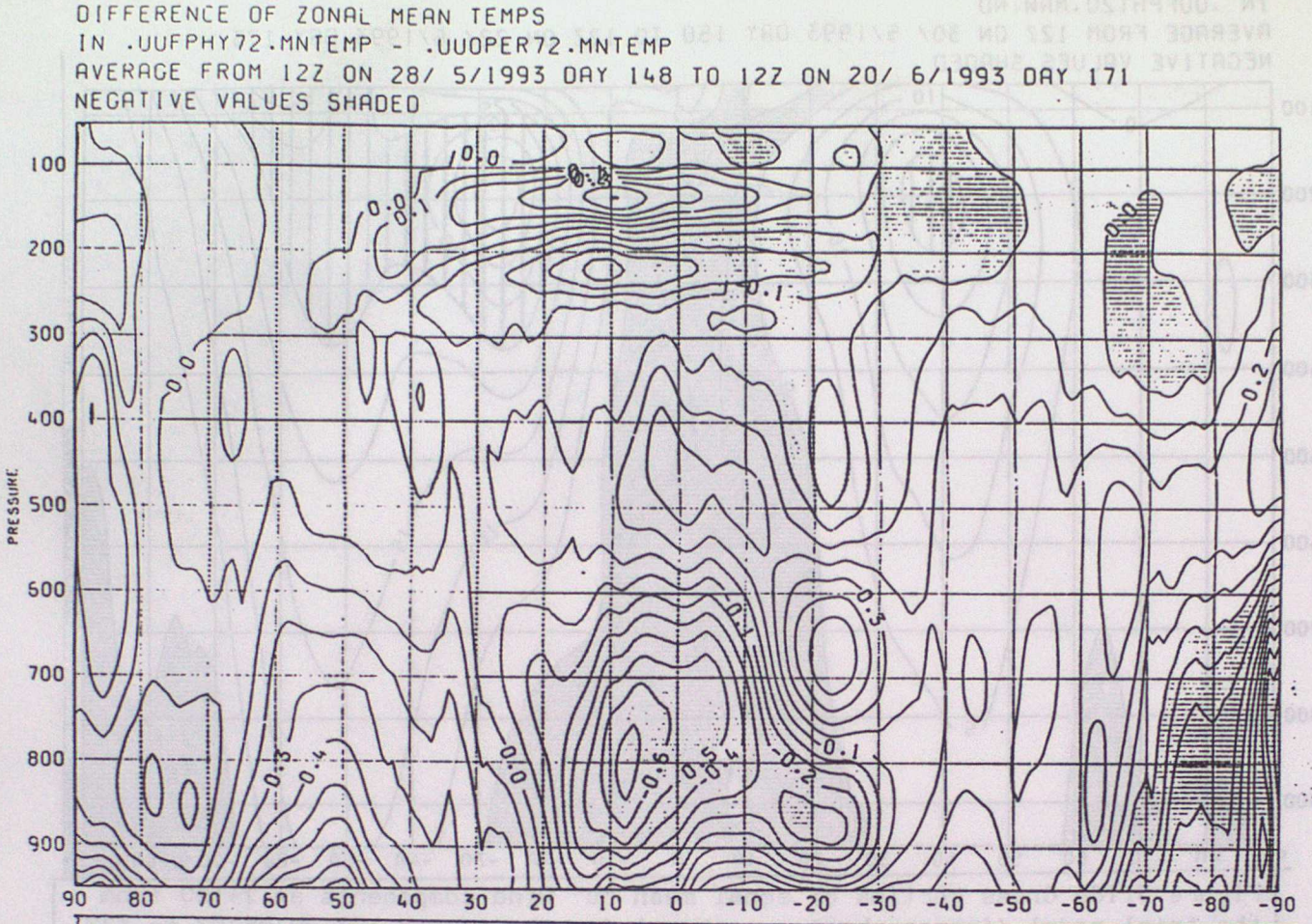


Figure 5.17a Cross section of zonal mean temperature differences at T+72 between the trial model (frozen physics package) and the operational model (trial-oper) for the period 12Z 28/05/93 to 12Z 20/06/92

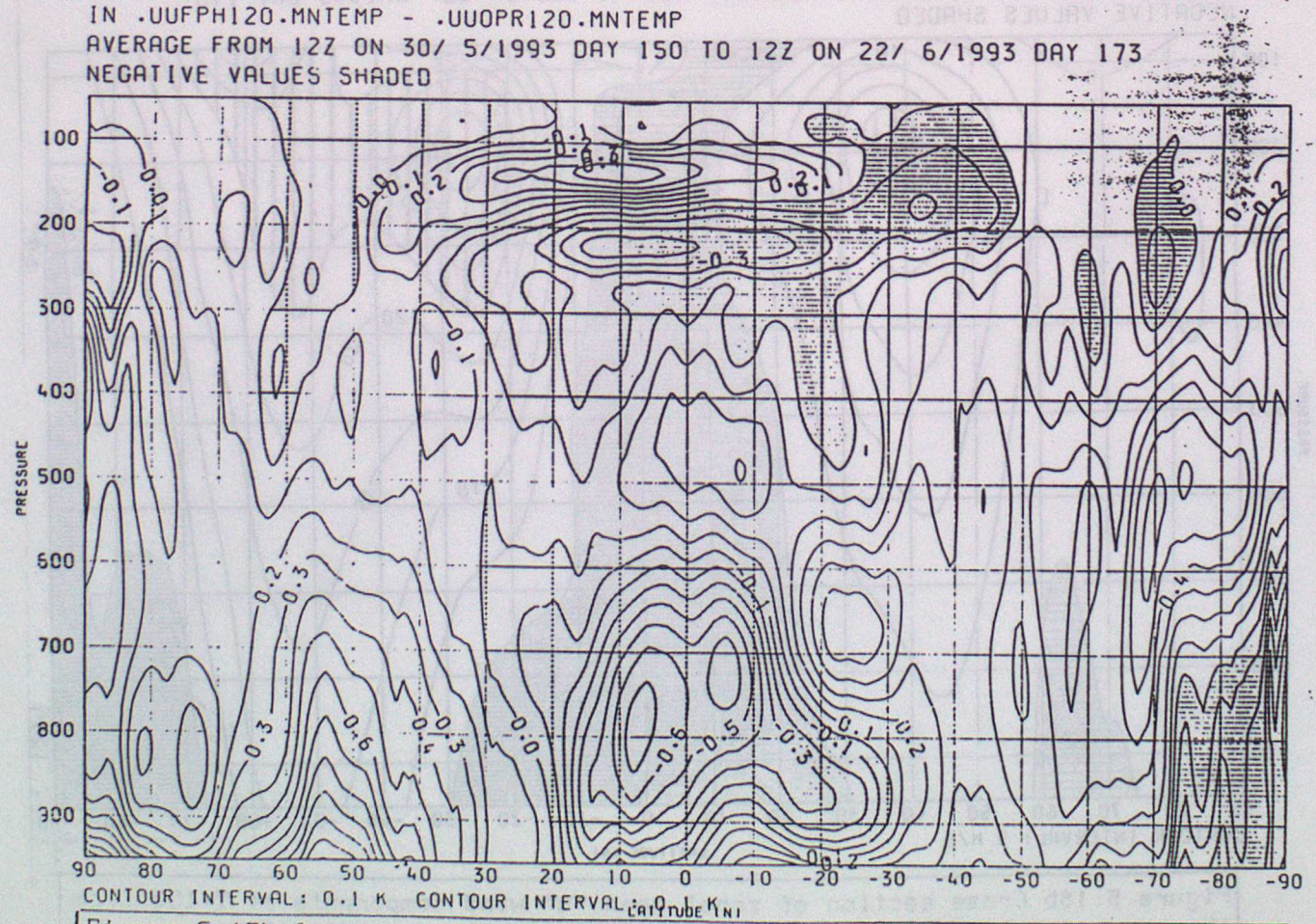


Figure 5.17b Cross section of zonal mean temperature differences at T+120 between the trial model (frozen physics package) and the operational model

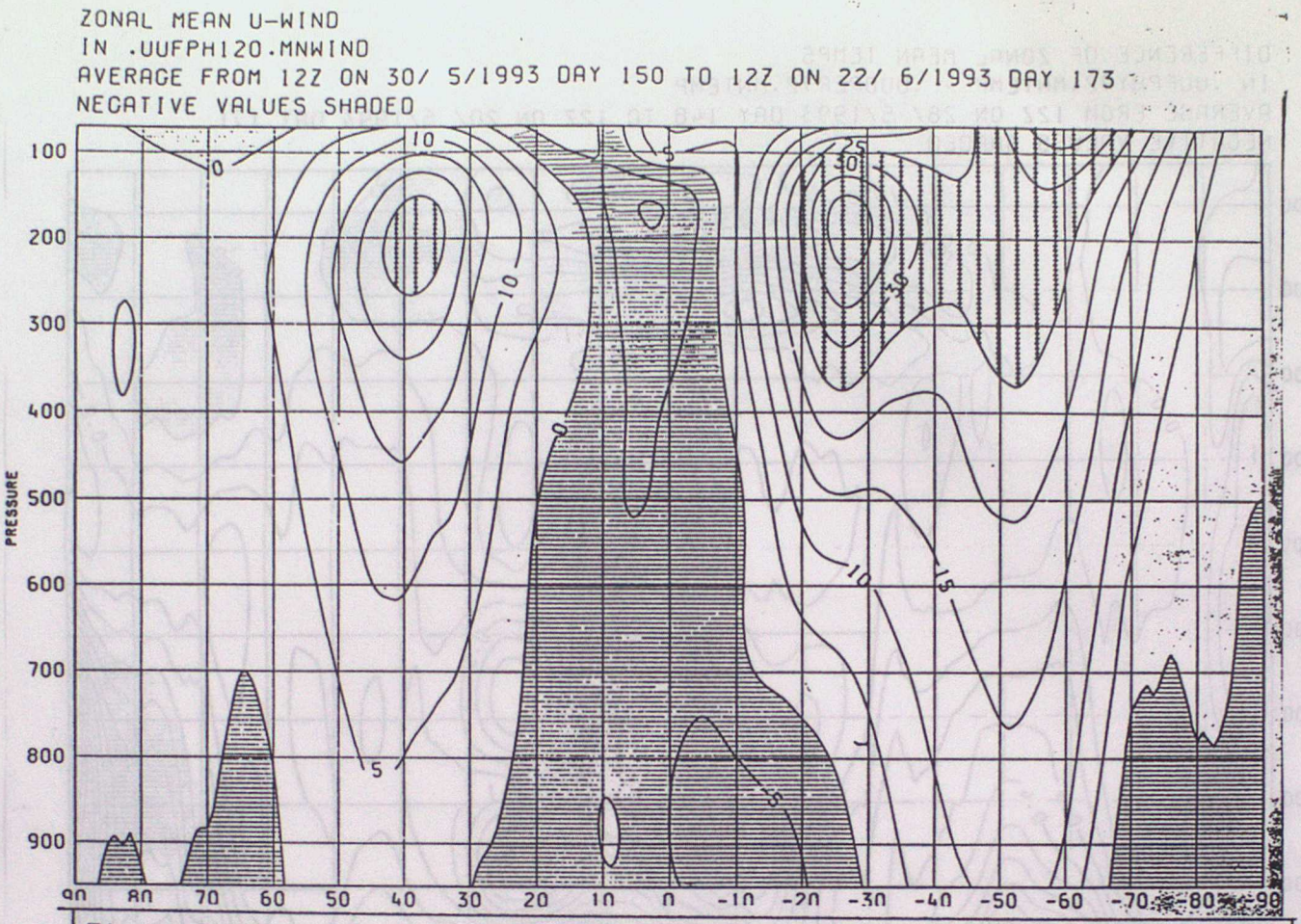


Figure 5.18a Cross section of zonal mean "u" wind components at T+120 from the trial model (frozen physics package) for the period 12Z 30/05/93 to 12Z 22/06/93

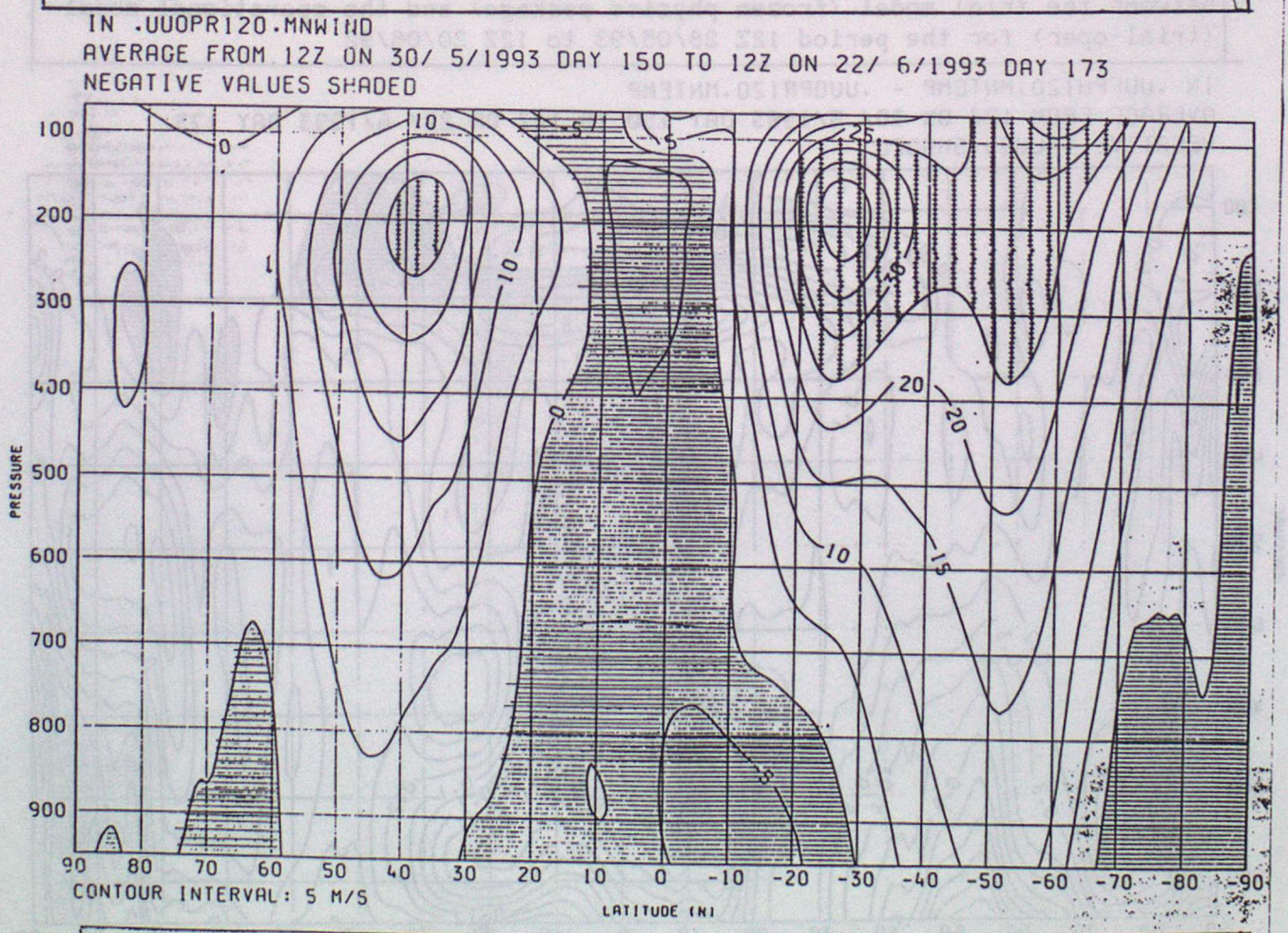
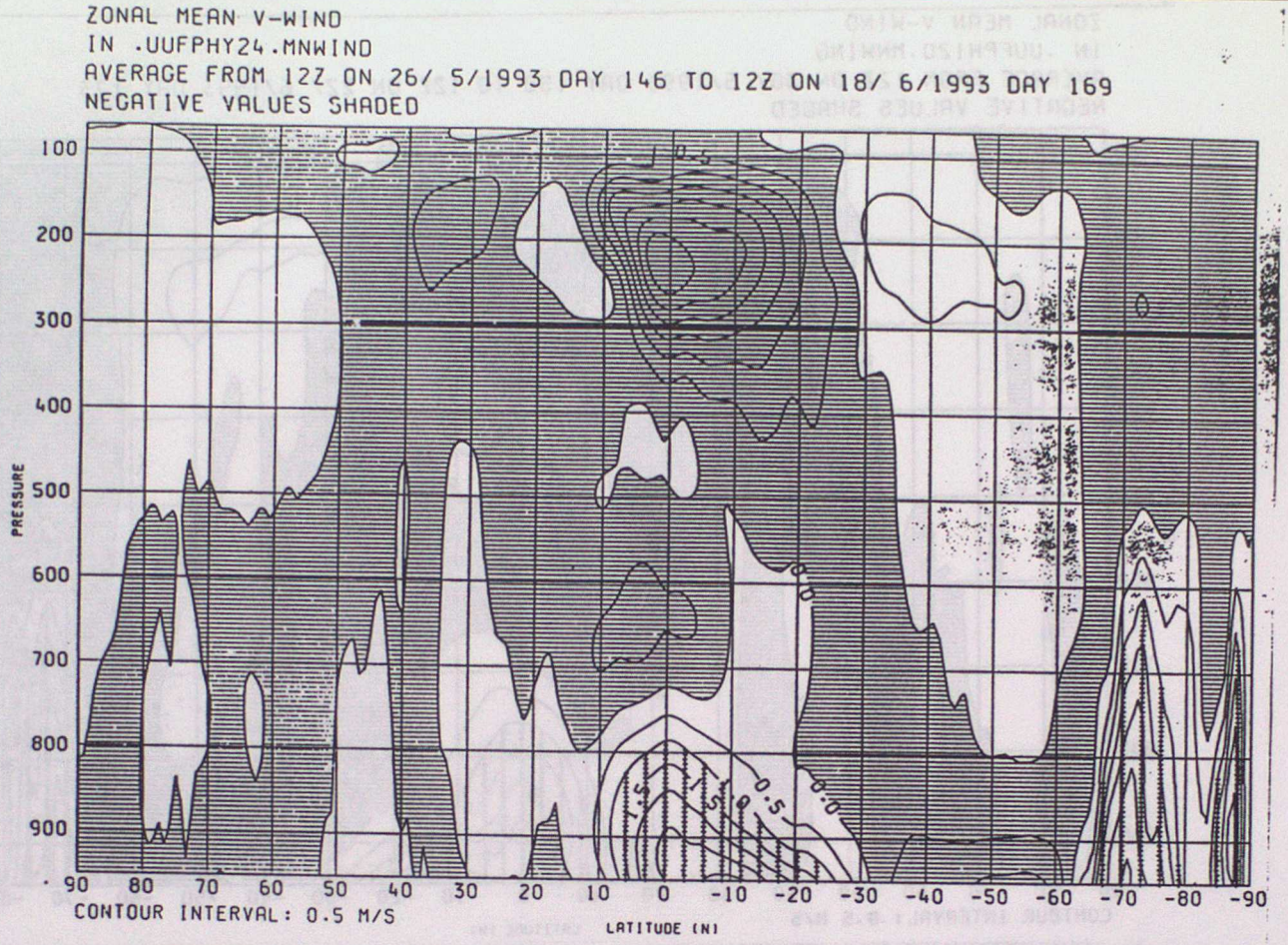


Figure 5.18b Cross section of zonal mean "u" wind components at T+120 from the operational model for the period 12Z 30/05/93 to 12Z 22/06/93

Figure 5.19a Cross section of zonal mean "v" wind components at T+24 from the trial model (frozen physics package) for the period 12Z 26/05/93 to 12Z 18/06/93



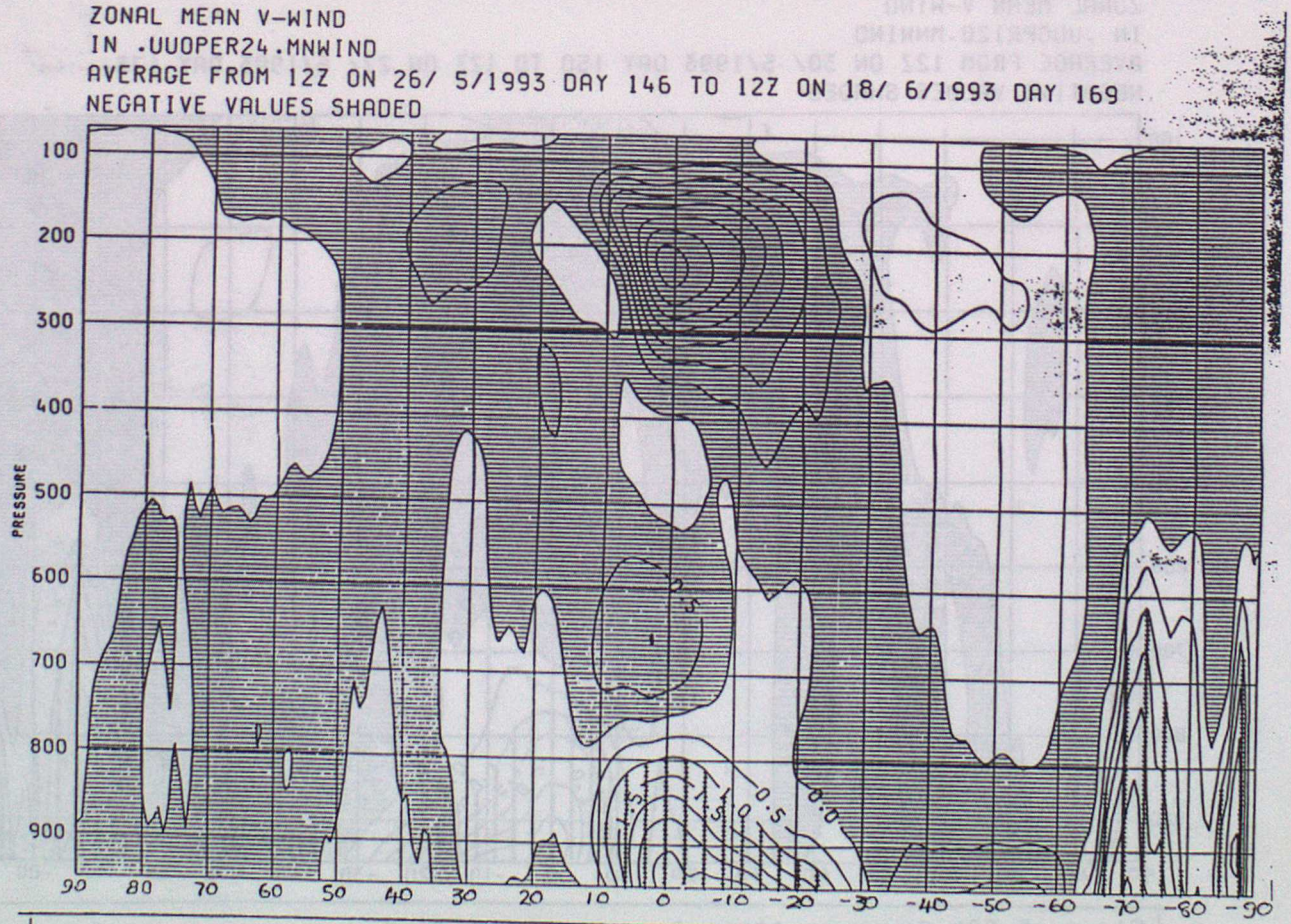
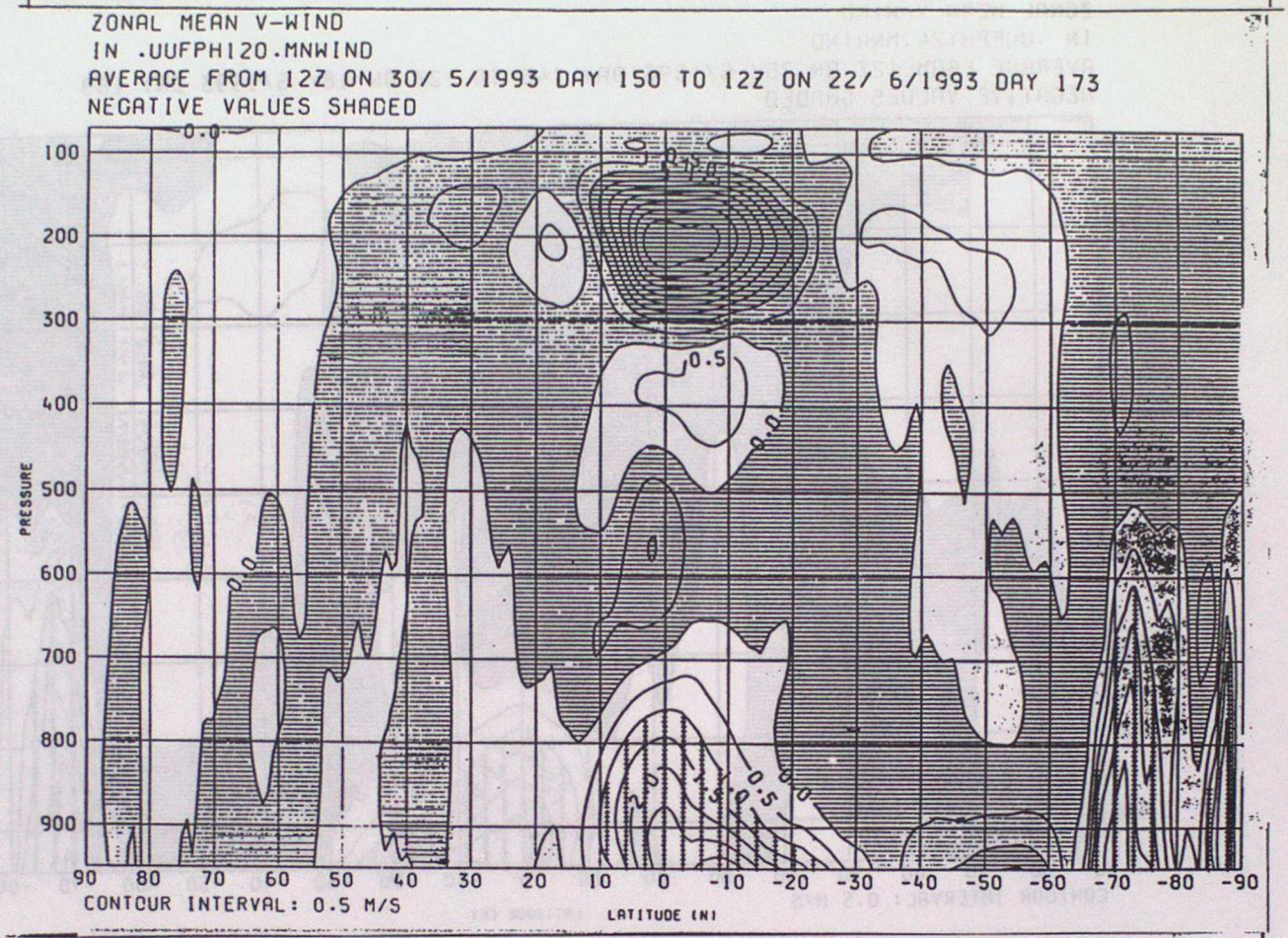


Figure 5.19b Cross section of zonal mean "v" wind components at T+24 from the operational model for the period 12Z 26/05/93 to 12Z 18/06/93

Figure 5.20a Cross section of zonal mean "v" wind components at T+120 from the trial model (frozen physics package) for the period 12Z 30/05/93 to 12Z 22/06/93



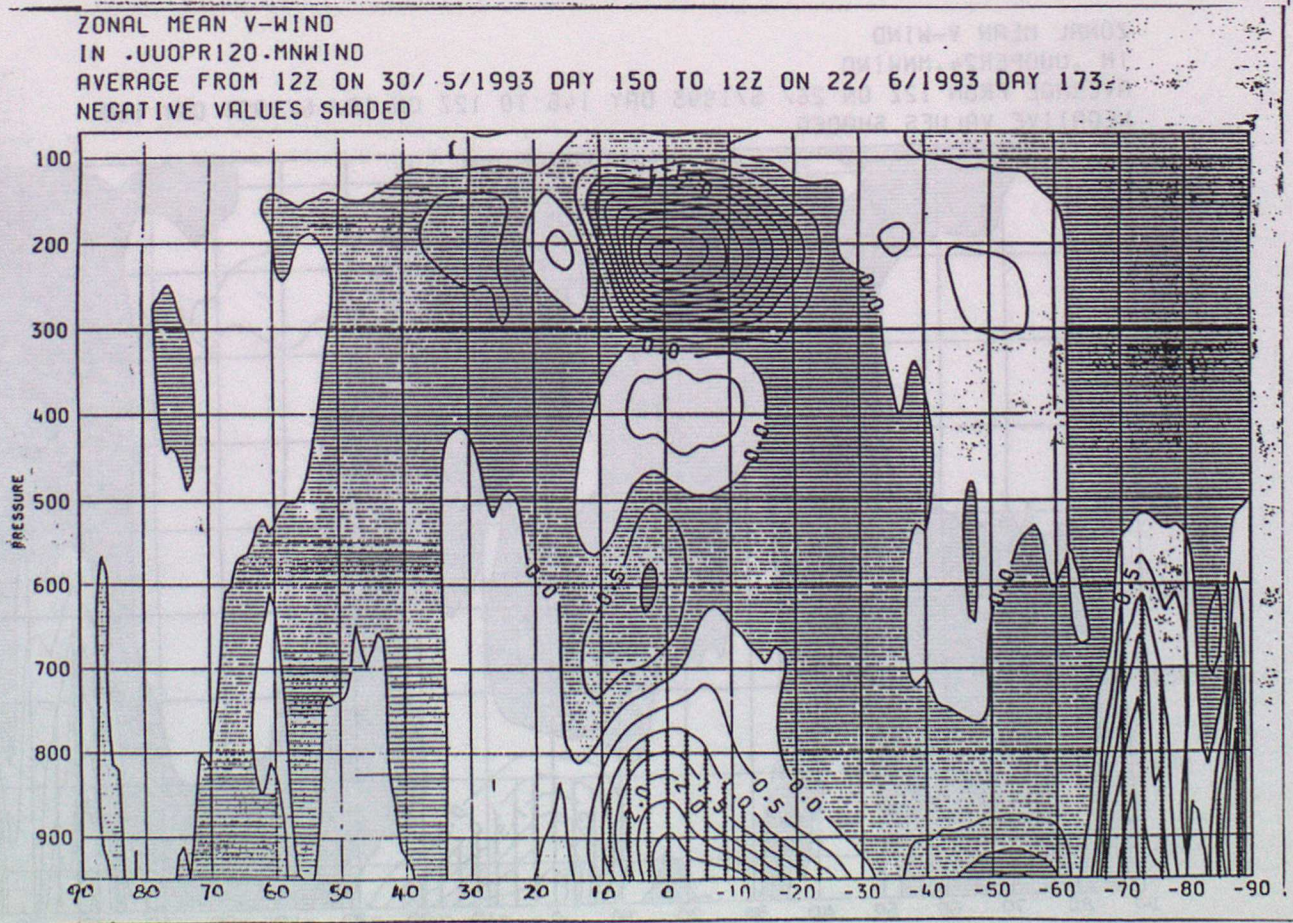
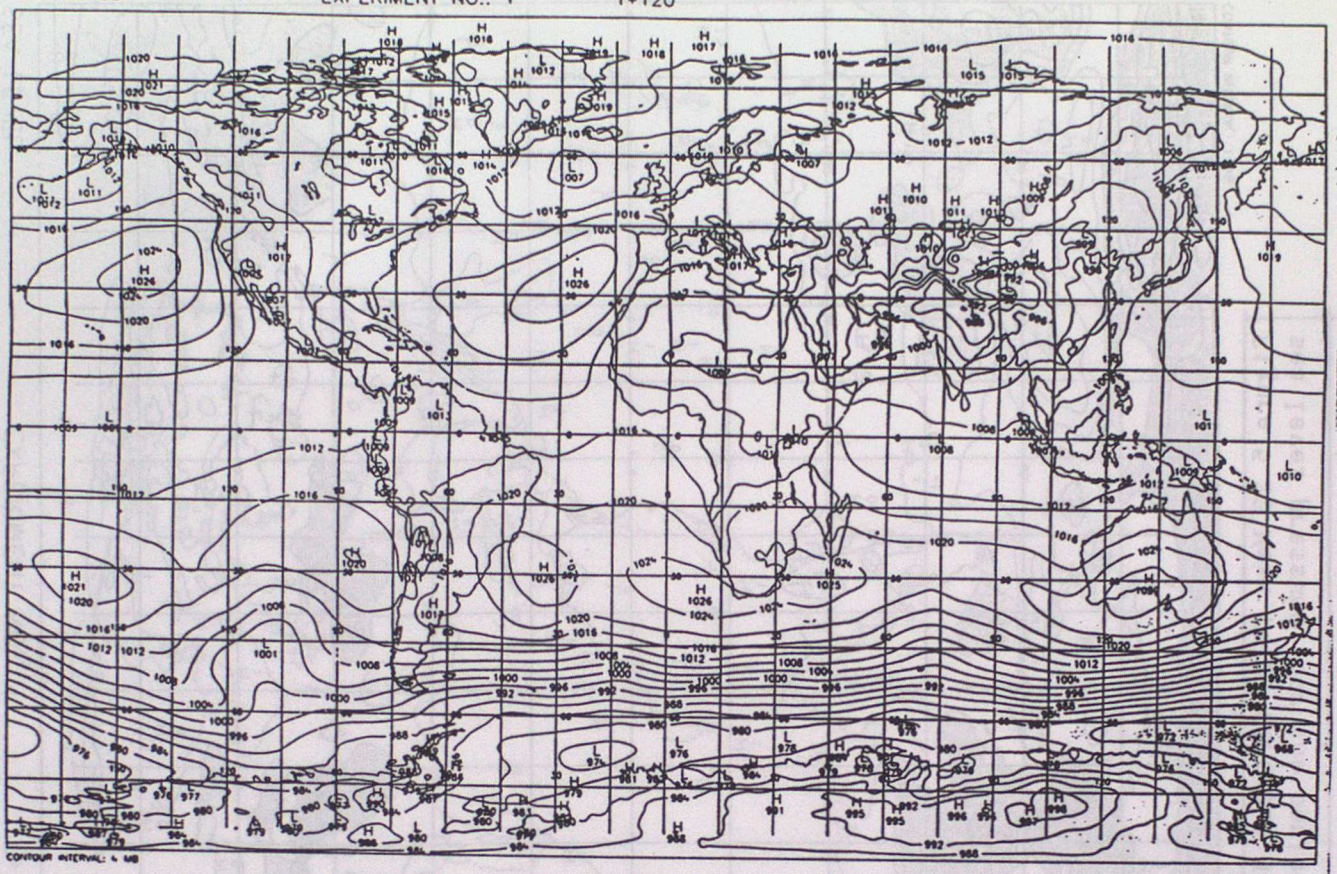


Figure 5.20b Cross section of zonal mean "v" wind components at T+120 from the operational model for the period 12Z 30/05/93 to 12Z 22/06/93

Figure 5.21a Mean T+120 forecast of mean sea level pressure from the trial model (frozen physics package) for the period 12Z 30/05/93 to 12Z 22/06/93.

MEAN SEA LEVEL PRESSURE - FROZEN PHYSICS
IN .UUFPHY.MSLP120M
AVERAGE FROM 12Z ON 30/5/1993 DAY 150 TO 12Z ON 22/6/1993 DAY 173
SEA LEVEL EXPERIMENT NO.: 1 T+120



MEAN SEA LEVEL PRESSURE CONTROL VERSION
IN .UUOPER.MSLP120M
AVERAGE FROM 12Z ON 30/5/1993 DAY 150 TO 12Z ON 22/6/1993 DAY 173
SEA LEVEL EXPERIMENT NO.: 1 T+120

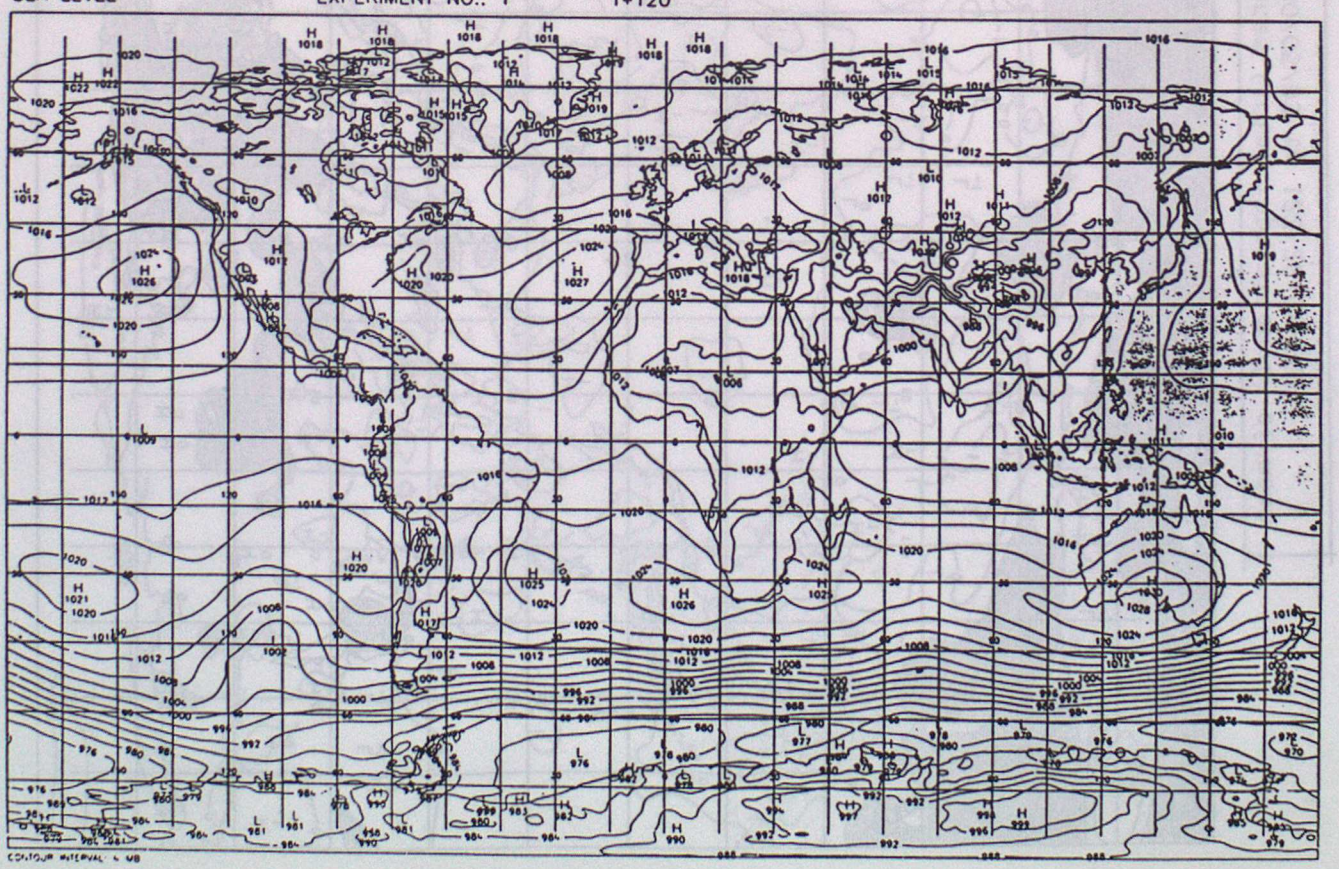
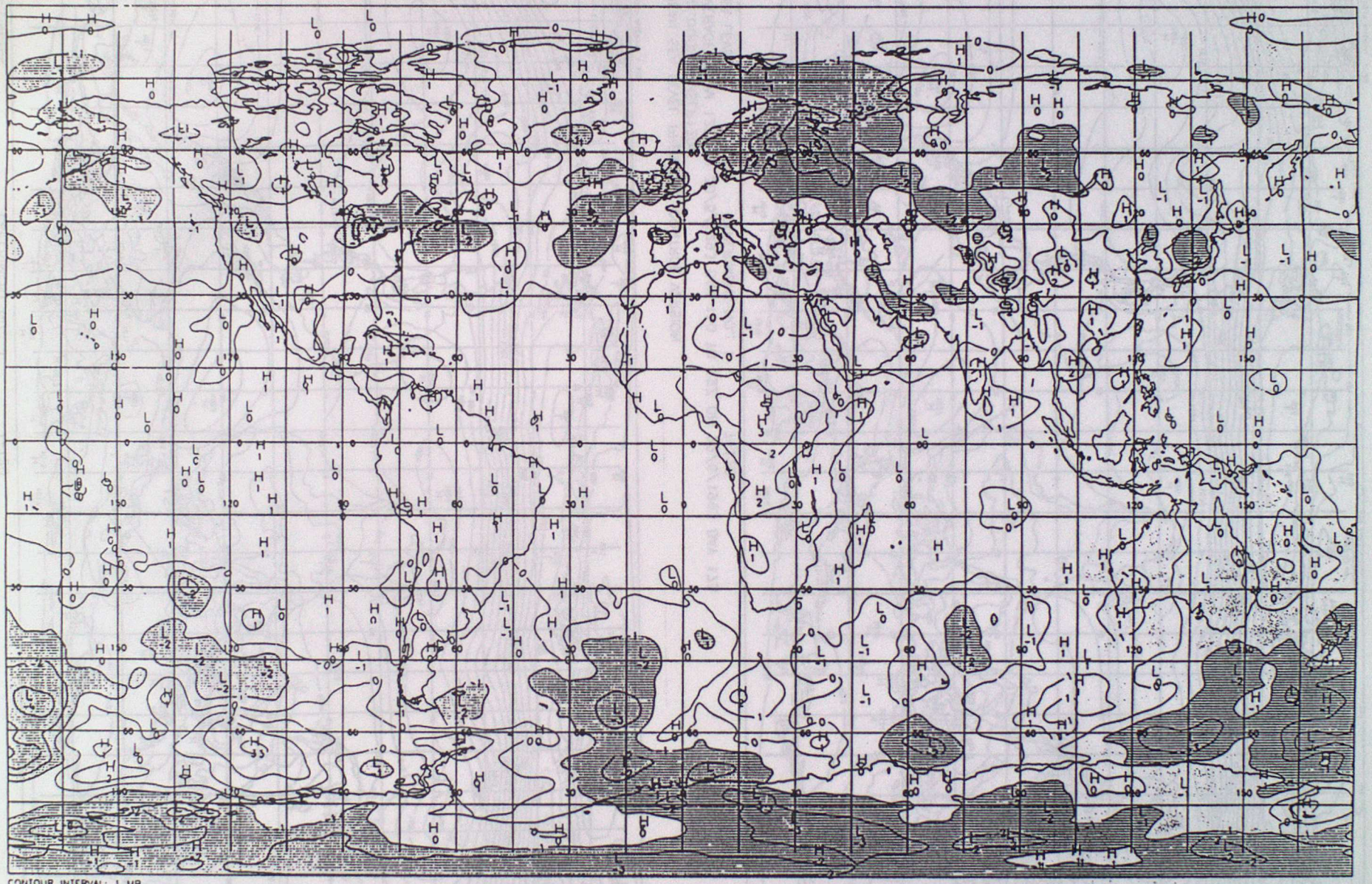


Figure 5.21b Mean T+120 forecast of mean sea level pressure from the operational model for the period 12Z 30/05/93 to 12Z 22/06/93.

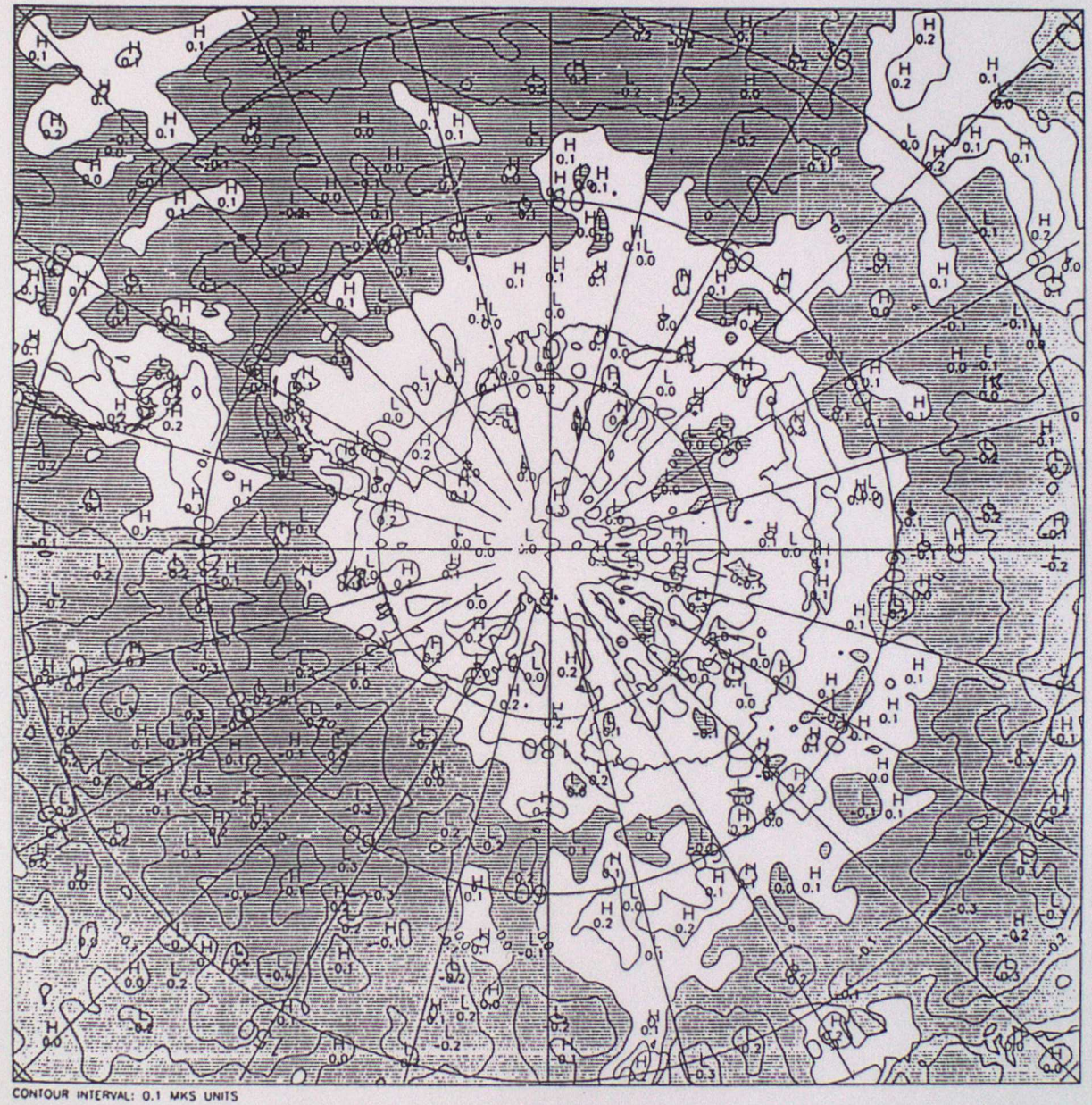
MEAN SEA LEVEL PRESSURE FPHY-OPER T+120
AVERAGE FROM 12Z ON 30/ 5/1993 DAY 150 TO 12Z ON 22/ 6/1993 DAY 173
SEA LEVEL EXPERIMENT NO.: 1 T+120



CONTOUR INTERVAL: 1 MB

Figure 5.22 Mean T+120 forecast differences (trial -operational) of mean sea level pressure for the period 12Z 30/05/93 to 12Z 22/06/93.

MEAN LOW CLOUD FPHY-OPER T+036
AVERAGE FROM 0Z ON 27/ 5/1993 DAY 147 TO 0Z ON 19/ 6/1993 DAY 170
EXPERIMENT NO.: 1 T+36



CONTOUR INTERVAL: 0.1 MKS UNITS

5.23 Mean differences at T+36 (trial - operational) in low cloud fraction